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Selecting Analytic Approaches for Decision Situations (Revised Edition)

VOLUME II: Case Studies

R.V. Brown
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SELECTING ANALYTIC APPROACHES FOR DECISION SITUATIONS (Revised Edition)

VOLUME II: CASE STUDIES

by

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The three volumes of this report present a conceptual framework within which experienced decision analysts can derive generalizations that match analytic techniques to decision situations and communicate those generalizations to decision makers and inexperienced analysts. The framework consists of a three-way taxonomy: decision situations, analytic options, and performance measures.

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The other two volumes of this report contain detailed descriptions of this framework; this volume contains five case applications of it. The framework is used to explain the choice of decision analytic techniques to apply to cases involving:

1. The problem of what foreign policy the U.S. should adopt in order to obtain more oil from a particular mideastern country.

2. A decision faced by the president of an electrical equipment company of whether to purchase the defense market rights to a flight safety patent.

3. A project undertaken by the Naval Electronics Systems Command (NAVELEX) to apply the "Design-to-Cost" concept to an evaluation of proposed electronic warfare systems.

4. A research and development project aimed at developing tactical decision aids for Navy task force commanders.

5. A study aimed at predicting NATO's response to actions taken by the Warsaw Pact countries.

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1.0 INTRODUCTION

This volume applies the matching principles and taxonomies introduced in Volume I and detailed in Volume III to five actual decision situations. The purpose of this volume is three-fold:

1. To illustrate the idea of matching principles.

2. To uncover weaknesses in the existing developments of the taxonomies and suggest ways of correcting these weaknesses.

3. To test the viability of the taxonomies as a framework for:

   a) Communicating matching principles to decision makers and decision analysts and

   b) Developing matching principles that identify the proper analytic techniques for decision situations.

Throughout this volume, our explanations of the reasons surrounding the choice of analytic techniques are stated in terms of the taxonomies, but the applications of matching principles are much more informal than those presented in the Export Control Decision (Section 4 of Volume I).

The five cases presented in this volume are:

Case 1 -- A Foreign Policy Decision

Case 2 -- A Business Investment Decision

Case 3 -- A Design-to-Cost Evaluation

Case 4 -- A Navy Task Force Commander's Tactical Decision Aid

Case 5 -- Predicting NATO's Response.

These cases were chosen to represent a broad range of situations in which decision analysis has been used successfully. The first case refers to the problem of what foreign policy position the US should adopt in order to obtain more oil from a particular mideastern country. The second case refers to a decision faced by the president of an electrical equipment company of whether to purchase manufacturing rights to a flight safety patent. The third case refers to a project undertaken by the Naval Electronics Systems Command to apply the "Design-to-Cost" concept to an evaluation of proposed electronic warfare systems. The fourth case refers to a research and development project aimed at developing tactical decision aids for Navy task force commanders. The fifth case refers to a study aimed at predicting NATO's response to actions by Warsaw Pact countries. We recognize that this choice of cases causes our presentation to be weighted heavily toward decisions that favor the use of at least some amount of decision analysis. However, decision analysis was generally justified by different combinations of reasons from case to case, and different specific analytic techniques were used in different cases.

The length of descriptions also varies with the cases. The first three presentations are longer than the last two. The lengths are indicative of both the number of important analytic techniques used in the cases and the extent to which the taxonomies were found to be useful in explaining the analytic choices. In most of the cases, we address our attention to only the most important analysis choices. However, in the second case, we present a more complete and extensive application of the taxonomies.

Although the applications of the matching principles to the cases were performed after the fact, we have generally attempted to reconstruct the events of the cases to illustrate how the matching principles might have been applied in the unfolding situation.

To obtain a complete understanding of the arguments presented in this volume, the reader may need to refer to the detailed descriptions of the taxonomies presented in Volume III. However, we consider such references unnecessary in a first reading. In addition, the reader may wish to refer to more technical descriptions of the case studies which are contained in other technical reports. Requests for copies of these reports should be addressed to:

Librarian
Decisions and Designs, Inc.
Suite 600
8400 Westpark Drive
McLean, Virginia 22101

Throughout this volume, references to the situation taxonomy of Section A, Volume III are prefixed with the letter "S," references to the analytic taxonomy of Section B, Volume III are prefixed with the letter "A," and references to the performance measure taxonomy of Section C, Volume III are prefixed with the letter "P."

2.0 CASE 1: A FOREIGN POLICY DECISION

2.1 Introduction

This case refers to a decision analysis of alternative foreign policy positions that the United States could adopt in order to obtain more oil from a particular Mideastern country. A technical description of this analysis appears in Brown, Peterson, and Ulvila (1975) and is not reproduced here.

2.1.1 Problem background - In the early 1970's, before the "energy crisis" of October 1973, U.S. government policy makers had begun to recognize the potential for such a crisis. U.S. energy needs were expected to climb steadily over the next decade. However, the supply of energy, which was hard-pressed to meet the current demand, was not expected to expand during this time. Thus, the prospects for the near-term future were that the supply of energy would fall seriously short of demand.

In response to these prospects, a top-level U.S. government policy maker (referenced as the policy maker in the future) established an inter-agency sub-committee composed of representatives from the Commerce Department, the Interior Department, the State Department, the Defense Department, and others. This sub-committee was charged with the responsibility of making a recommendation of a foreign policy position that would improve the supply of oil to the U.S. The chairman of the committee (referenced as the chairman in the future), a government policy advisor, was ultimately responsible for making the recommendation to the policy maker.

As the committee began to investigate the problem, its chairman felt that the deliberations were especially disconnected, haphazard, vague, and unproductive. This situation was especially discomforting to the chairman because he knew that his boss, the policy maker, demanded carefully reasoned and logically consistent policy recommendations. Thus the chairman was convinced that his recommendation would not be acted upon unless it was based upon careful and consistent reasoning.

The chairman was familiar with the efforts of Decisions and Designs, Inc. (DDI) in applying decision analysis to government policy questions. He felt that their methodology might help him sort through the vast amount of information that he had obtained about his problem from various experts and help him to build a logically sound recommendation. With this in mind, the chairman contacted DDI to initiate a decision analysis of this problem.

2.1.2 Use of decision analysis - This project represented an initial attempt of the chairman to apply decision analysis. As such, this analysis was viewed as an opportunity to experiment with a new approach to policy analysis. If this experiment proved successful, it was likely that the chairman would use decision analysis for future policy analyses.

The first task in the analysis was to define the decision options. Within the main problem area of improving the oil position of the U.S., the committee saw an agreement with a Mideastern oil-producing country as the most promising region for investigation. However, even within this narrowly defined region, the possible range of agreements was enormous, and their effects would be wide and far reaching.

The analysis eventually settled down to an investigation of unilateral concessions that the U.S. could make to a particular mideastern country. The chairman felt that the U.S. could offer the most to this country along four main dimensions: political support, military support, dollar absorption, and cultural exchange. Within the context of these dimensions, three representative concessions were structured for future evaluation in the analysis.

Although these three concessions would impact on a wide range of U.S. interests, the chairman was willing to evaluate them on the basis of their impacts on five key U.S. interests. The first interest was the effect that the concession would have on the volume and price of oil that the mideastern country would offer to the U.S. The second interest was the effect of the concession on the United State's balance of payments. Third was the effect on the relationship between the U.S. and its allies. Fourth were the sentiments of the U.S. public to the concession. Fifth was the effect that the concession would have on the oil that other countries would make available to the U.S.

It was readily apparent to both the chairman and the analysts that the effects of the concessions on the valuation criteria were very uncertain. Furthermore, the valuation criteria themselves were imprecisely defined. In particular, they could be subdivided very easily into many component parts.

The role of the decision analysis was, then, to generate decision options that could be analyzed, structure a framework for the analysis, and use the judgments of various experts to arrive at a policy recommendation.

2.2 Performance Determinants of a Good Analysis

The important situation characteristics of this case can be distilled in the form of performance measures. This particular case required three major types of performance. The analysis had to process inputs effectively, reach a logically sound decision, and communicate its reasoning. In addition, the cost of the analysis could not overrun the budget.

A large quantity of data was available at the beginning of the case. Because this data was vital to the decision, the most important measure of the quality of the analysis was its ability to process the existing data inputs (P122).[1] In addition, the situation was characterized by options, values, and uncertainties that were all difficult to define and assess. Thus another component of input processing was the ability of the analysis to pose meaningful questions about options, values, and uncertainties to the assessors (P123).

Because the stakes involved in the analysis were high (S1444)[2] and the best decision was not obvious (S1334), the quality of the reasoning and logic contained in the analysis (P144) was the second most important measure of a good analysis. Three components of logic were most important. In descending order of importance the components were, first, the analysis had to provide an effective disaggregation of the problem (P112); it had to divide the problem into manageable sub-problems. Second, the analysis had to address the

[1] References that begin with the letter "P" are performance measures, which are explained in detail in Appendix C of Brown and Ulvila (1977).

[2] References that begin with the letter "S" are situation characteristics, which are explained in Section 2.5 below.

entire problem (P115), not just a part of the problem such as the assessment of probabilities. Third, the analysis had to be conceptually complete (P111); it had to account for all important considerations and avoid serious approximation errors.

The third most important measure of a good analysis was its ability to communicate the reasons for a decision (P321). This performance measure was especially important in this case because the decision maker would have to justify his decision to his boss and to others.

2.3 Analytic Choices

The recommended analytic options for this case are summarized on Table 2-1. The following sections explain the reasoning behind the most important choices.

2.3.1 Choice of the amount of analysis - Section 3.1.2 of Volume I contains an explanation of the guidelines for determining the proper amount of decision analysis in terms of situational characteristics. The decision maker could have characterized his situation along these dimensions to determine the proper amount of decision analysis as follows.

Important factors favoring a large amount of decision analysis:

- The choice of the best foreign policy recommendation was difficult (S1313).

- The choice involved high stakes. The expected difference in value among the reasonable options was on the order of several hundred million dollars of the U.S. federal budget (S1444).

1 USER'S OPTIONS

11 USE DECISION ANALYSIS AT ALL?

112 yes

12 DOLLAR AMOUNT OF ANALYSIS

122 medium

13 ROLE OF DECISION ANALYSIS

1312 public
1322 optional
1342 display

14 ORGANIZATION

1419 consultants to perform the analysis
1421&3 decision makers and experts to provide inputs
1421 close relationship with decision maker

15 RESOURCES

1511 decision analysis specialists
1521 computer

2 MODEL APPROACH OPTIONS

21 COMPLEXITY OF ANALYSIS

212 moderately complex

22 COMPREHENSIVE OR PARTIAL

2223 partial on options

23 DEGREE OF APPROXIMATION

232 medium exactness

24 BALANCE OF EFFORT

2412 appreciable effort on option definition
24212 moderate effort on uncertainty modeling
24222 moderate effort on value modeling

3 INPUT STRUCTURE

31 UNCERTAINTY

3110 certainty equivalents
3121 short time horizon
3130 no subsequent acts
3141 low detail
3152 high degree of grouping

32 VALUE

3213 comprehensive
32312 single utility index
32411 linear value function

4 INPUT SPECIFICATION

43 VALUE CRITERIA

4319 mixture of units
4322 "floating-zero" base

45 ELICITATION TECHNIQUE

4512 direct for probabilities
4532 direct for values

5 OUTPUT

51 SPECIFICATION

5121 single value for each option

52 DISPLAY FORMAT

5211 graphic

Table 2-1

SUMMARY OF THE ANALYSIS CHOICES FOR THE FOREIGN POLICY DECISION

- o Many sources of inputs were vital to the decision (S2215).

- o The decision maker was required to justify his decision to his boss and to others (S2343).

- o The decision maker was familiar with decision analysis (S24212).

Important factors against a large decision analysis:

- o The available decision options were not clearly defined (S1222).

- o Option generation, rather than choice, was the key determinant of a good decision (S1331).

Other factors favoring a large decision analysis:

- o The choice was current; the chairman would make a recommendation in 60 days (S1111).

- o The chairman expected to make very similar decisions in the future (S1124).

- o The outcomes were difficult to evaluate on the value dimensions (S1512).

- o The uncertain quantities were difficult to assess (S1621).

- o The decision maker had a relatively long time, 60 days, to make his recommendation (S214).

- This analysis was considered a training project and it might determine whether decision analysis would be used in the future (S2252).

- The "rational actor" model, which hypothesizes a single decision maker who relies on reasoned judgments in making his decisions, fits this case very well (S2372).

- Computer facilities were readily available (S2512).

- A strong staff was available (S2522).

- The decision maker was available for frequent interactions with the analysts (S2542).

Another factor against a large decision analysis:

- Only a modest budget was available for the analysis (S2562).

In this case, many more factors argued for using a large amount of decision analysis than argued against it. Most importantly, the stakes in the decision were high, the choice was fairly difficult, and enough time was available to perform a large analysis. Thus, the decision situation indicated that a large decision analysis was needed. However, only a modest budget was available for the analysis, so a large analysis was impossible. Therefore, the size of the analysis was ultimately decided by the size of the analysis budget.

2.3.2 <u>Type of analysis</u> - The following ten analytic choices were made mainly by the decision analysts during the course of the analysis effort.

The first major analytic choice was whose point of view the model should take. In making his recommendation, the decision maker was motivated to consider what was best for the United States, rather than what was best for himself personally. Thus, the analysis should have taken the role of a public analysis (A1312), one that is performed for the benefit of an institution rather than an individual. This was done in the actual analysis.

The second major analytic choice was to build a partial model of the decision options (A2223) initially and to complete this part of the model as dictated by a sensitivity analysis. In this case, the possible decision options were very numerous and complex (S1236) so it was important to try to develop the analysis on a few fairly obvious options before attempting to evaluate other options. This strategy was particularly appropriate in this case because it was likely that an analysis developed on a few obvious decision options would apply to other options. That is, the structure appropriate for analyzing a few options would also be appropriate for analyzing most of the other options.

The reader should notice that the reasoning surrounding this analytic choice does not fit conveniently into the framework of the taxonomies as they are currently developed. This is because it is impossible to describe decision situations in a way that is universally applicable to all analytic choices without using a much finer level of detail than is currently developed in the taxonomies. At the present level of development, the right way to describe a situation for one choice may differ from the right way to describe a situation for another choice. This problem can be overcome by developing the existing universal taxonomies to a finer level of detail or by developing taxonomies that

are specific to particular fields of decision making. (The idea of specific taxonomies is explained in greater detail in Section 4.2.2 of Volume I.) However, such a development would be a very major undertaking and is outside of the scope of the present project.

The third major analytic choice was to use the analysis in a display mode (A1342). That is, the choice was made to use the analysis to display the considerations surrounding the decision rather than to show only the optimum decision. We would almost always recommend some amount of display, but in this case, because the decision needed to be justified (S2343) and the decision options were modeled partially (A2223), the display mode was especially important.

The fourth major analytic choice concerned the balance of effort among the various parts of the analysis. In the actual analysis, approximately 90% of the effort was spent on developing several detailed models of the oil that the Mideastern country would make available to the U.S. In retrospect, the balance of effort should have been spread more evenly across the various analysis areas. In particular, because the value judgments were controversial (S2352), a much larger portion of the effort should have been allocated to making the tradeoffs among the value dimensions (A24222). Also, because component valuation was difficult (S1563), slightly more of the remaining (reduced) amount of effort to be devoted to modeling the uncertain outcomes (A24212) should have been devoted to modeling the other outcomes of allied goodwill, U.S. sentiments, and balance of payments. The allied goodwill dimension should have been decomposed into the effect of the decision options on each of several allies, such as Germany, France, and Japan. The U.S. sentiment dimension should have considered different segments of the

U.S. population. The balance of payments dimension should have been decomposed into elements such as export business, import business, oil imports, and so forth. The overall effects of these recommendations would be to greatly reduce the percentage of analytic effort spent on the models of oil. The taxonomic framework may have helped the analysts in this case to avoid this problem by bringing the question of the proper balance of effort to their attention. Such prompting may have corrected their tendency to prematurely limit the analysts by modeling what was most immediately accessible to them.[3]

The fifth major analytic choice was to convert all outcome valuations to a single index, dollars in the U.S. federal budget (S32312). This choice was indicated because the evaluations of the outcomes along the five dimensions of value did not combine naturally (S1541). In particular, values were expressed in:

- Barrels per day and dollars on the value dimension of oil from the Mideastern country.
- Dollars on the value dimension of balance of payments.
- Abstract utility units on the three value dimensions of allied goodwill, U.S. sentiments, and other sources of oil.

---

[3]Another example of a case where the analysts yielded to temptation to model the most immediately accurate part of the problem is documented in the Allied case (pp. 520-547 of Brown, Kahr, and Peterson [1974]). In that case, the analysts decided immediately to model the value of Allied's shock absorber business rather than the more appropriate (by hindsight) decision of what they could do if they left the shock absorber business.

The attractiveness of the decision options would be impossible to determine by trading off these value units directly. Thus, everything was converted into a single measure. In addition, the particular measure, federal budget dollars, was chosen because utility was assessed as linear with federal budget dollars; and this measure was one that the policy maker, who would actually act on the recommendation, could easily understand.

Two other methods of arriving at a single valuation measure were considered, but these were not as attractive as converting all of the values into federal budget dollars. First, all of the values could have been converted into an abstract utility figure, but the meaning of the figure would have been very difficult to communicate to the policy maker (who was unfamiliar with decision analysis). Second, all of the values could have been converted into the units of one of the components (e.g. barrels per day of oil). This was not done because utility was non-linear in each component's value dimension. Thus, assessments would be much more difficult if a component's value measure was used instead of the linear measure of federal budget dollars.

The sixth analytic choice was to use three parallel approaches to modeling the uncertainty, "oil from the Mideastern country." Using several approaches for the same uncertainty improved the logic of the analysis (P11) by providing several checks on the accuracy of the assessment. In this case, three models of the same quantity yielded similar outputs. A further argument for this approach is that the uncertain quantity lent itself naturally to the use of several modeling techniques. Thus, the parallel models could be built relatively quickly and easily.

In particular, three approaches were used: direct assessment, conditioned assessment, and joint assessment. In the direct assessment, the assessor specified a probability distribution of the volume of oil that the Mideastern country would make available to the U.S. under each of the three decision options. The direct method was used because it is generally the easiest method to use if the assessors are willing to express their judgments directly, as they were in this case. The conditioned assessment of oil volume was indicated because this was the most natural way for the assessors to think about oil volume. That is, even though the assessors were willing to make direct judgments on the volume of oil, their first reaction to questions about this volume was, "It all depends." A conditioned assessment model explicitly treats the dependencies and thus was a natural model to use in this case. The joint distribution model, which called for an assessment of the joint probability distribution of the price of oil and the volume of oil, was used because the decision maker was predisposed to evaluate the attractiveness of the concessions based on both the price and volume of oil that would result. Thus, the joint assessment was chosen because it made valuation easier. This method, however, made the assessment of the uncertainty very difficult. In particular, the method required the analysts to develop a new analytic method for eliciting the joint distribution. In retrospect, this approach should not have been used, since it was too elaborate and sophisticated to be communicated effectively. In addition, using this approach contributed to the disproportionate amount of effort spent on the model of oil from the Mideastern country.

The seventh main analytic choice was to obtain inputs for the model using informal group elicitation techniques (A45411). This choice was indicated because the

views of many experts needed to be considered in the analysis (S2215), and group elicitation methods are the cheapest ways to extract the opinions of all of the experts. The informal method was indicated, rather than, for instance, the Delphi method, because each expert's status was the same, but each was an authority in a different subject area (e.g., politics, economics, and the oil industry).

The eighth major analytic choice was to use the method of "swing weights" to evaluate the outcomes of the decision options and aggregate those values into a single figure. This method of swing weights combines three analytic techniques. First, a "floating zero" base (A4322) was used for the outcome valuations. On each value dimension, the value of each decision option was measured relative to the value of the "baseline" of "no change in policy." Second, the units of value were defined by specifying, on each value dimension, the "swing" in value between best decision option and worst decision option as 100 units (A4319). Third, the tradeoffs among value swings on the dimensions were specified as "weights," thus forming a linear value function (A32411).

This method was chosen because it promoted a compact elicitation of values that was easy to communicate to the decision maker. This method is compact because it only poses questions that are directly relevant to the problems being analyzed. That is, the elicitations that are used to establish the value scales also serve to evaluate the decision options on those scales. Other forms of value models may require separate elicitations just to establish the value scale. In addition, the value scales are easy to communicate because they are directly tied to the options being evaluated.

These features make the swing-weight method an efficient one for analyzing a particular problem, but they also tie the value scale to the analysis in such a way that it becomes very difficult to use for other problems. That is, a swing-weight value scale that is developed for one analysis cannot be used easily in another analysis that requires the same value scales but contains different decision options. This is because the scales are defined by the particular decision options. Since in this case, the analysis was expected to be used on a recurring basis for similar decision problems (S1123), the swing-weight method should not have been used.

Alternatively, more effort should have been spent to establish an absolute scale for each value dimension that could be used for subsequent recurring analyses. For instance, the range of the allied goodwill scale may have been defined as the difference between the goodwill at the height of the Vietnam War and the goodwill right after World War II.

Another drawback to the swing-weight method is that it assumes that a linear combination of the different valuation criteria is the appropriate way to combine them into a single figure. In this case, this linearity condition did not hold strictly, but the cost of building a non-linear model was large (P222), and its contribution to the improved logic of the analysis was small (P114).

Note that this analytic choice does not fit conveniently into a single taxonomic category but is composed of several categories. This suggests that special taxonomies may be appropriate for analytic choices as well as for situations. (These special situation taxonomies are discussed in Section 4.2.2 of Volume I.) Such special

taxonomies would contain classifications of analytic options such as "swing weights," which would completely describe analytic methods in a form that is readily recognizable to certain observers, but would require different taxonomies for different observers.

The ninth analytic choice was to evaluate the decision options directly using certainty equivalents (A3110) rather than to assess probability distributions over the outcomes that might result from the choice of those options (for all value dimensions except "oil from the Mideastern country"). This feature required the value assessor to consider implicitly the uncertainties in the problem. Thus, the method is most applicable when a single person has access to both the information necessary to make value judgments and information pertinent to the uncertainties of the situation. Here, this condition held for all value judgments except those related to the dimension "oil from the Mideastern country."

The tenth analytic choice was to elicit the utility function for "oil from the Mideastern country" using direct rating (A4532) rather than using an indirect technique such as reference gambles. In general, the reference-gamble technique is very costly (P222) and time consuming (P212) to use unless the decision maker is very familiar with decision analysis (S24213), which was not the case here. In addition, unless the decision maker is very familiar with decision analysis, he is likely to give illogical responses (P114) to the questions required during a reference-gamble elicitation. Thus the use of the reference-gamble technique was not indicated as a primary elicitation technique in this situation. However, the reference-gamble framework was used to feed back the implications of the direct elicitation to the decision maker and thus to refine the original direct elicitation. (This refinement used the reference gamble as a null

instrument. That is, the decision maker had to respond only that he agreed or disagreed with the implication of his direct rating; he did not have to respond to elicitation questions with a probability or a value.) We recommend this use of the reference-gamble technique when the decision maker has a limited familiarity with decision analysis.

2.4 Conclusions

In this case, the taxonomic framework seems to serve well the purpose of determining how much decision analysis to use. However, two characteristics, the large stakes involved and the difficulty of the choice, would have been sufficient to indicate that a large analysis was justified. In addition, a single characteristic, the size of the analysis budget, was sufficient to determine the amount of analysis that could actually be done.

For other analytic choices, however, the taxonomies, at their current level of development, do not appear to be very helpful in general. Even though most of the reasoning surrounding the choices can be explained in terms of elements in the taxonomies, it would have been very difficult for most analytic choices to apply the taxonomies directly in the course of the unfolding situation. Such an application may require the development of a sequential matching procedure such as that suggested in Section 4.2.1 of Volume I. In addition, some of the analytic choices, such as the choice to build a partial model of the decision options (A2223), cannot be explained easily using the taxonomies in their present form. This problem may be overcome by developing the taxonomies to a much finer level of detail. However, such a development is outside of the scope of the current effort and may even prove to be a completely unmanageable task. Alternatively, the problem may be overcome by

the development of specific taxonomies (as suggested by Section 4.2.2 of Volume I). Again, the development of such taxonomies is outside of the scope of the present effort.

On the other hand, even the current development of the taxonomies may have been helpful in making some of the specific analytic choices. Specifically, the balance of effort may have been improved and the choice to use certainty equivalents may have been facilitated if the taxonomy had been available to the decision analysts.

2.5 Appendix: Situation Characterization

This appendix characterizes the foreign policy case along the dimensions of the situation taxonomy that is described in Section A of Volume III. A summary of this characterization is presented in Table 2-2.

1 Decision Substance

11 Basic Situation

1111 Current Choice. The problem was to decide immediately on a policy recommendation.

1123 Few recurrences. The policy advisor expected to make recommendations similar to this one several times within the next few years.

1131 Operating act. The action was what policy to recommend, not whether to seek information about the situation.

12 Options

1 DECISION SUBSTANCE

11 BASIC SITUATION

1111 current choice
1123 few expected recurrences
1131 operating act

12 OPTIONS

1211 broad
1222 fuzzy
1236 many possible choices
1241 radical
1252 dynamic

13 EASE OF DECISION

1313 difficult
1322 unfamiliar to decision maker
1331 option generation is key consideration

14 STAKES

1444 maximum option impact greater than $10 million

15 OUTCOME VALUATION

1512 very difficult net valuation
1523 many value dimensions
1531 approximate metric
1541 low combinability
1552 medium time horizon
1563 difficult component valuation

16 OUTCOME UNCERTAINTY

1613 many uncertainties
1621 difficult to assess
1632 medium amount of uncertainty
1641 low impact of subsequent acts
1652 lends itself to indirect techniques
1662 medium hindsight

2 DECISION PROCESS

21 REACTION TIME

214 months

22 ANALYTIC PROCESSES

2215 many import sources
22212 } group of decision
22223 } analysis consultants
2230 no constraints on analytic methods
2242 specific documentation format
2252 training project

23 ORGANIZATIONAL PROCESSES

23111 spontaneous initiation
23123 decision initiated by superior
23213 recommendation
2331 moderate coordination
2343 pre- and post-decision justification
2352 very controversial
2361 loose control of decision maker
2372 "rational actor" model
2381 risk averse

24 DECISION MAKER CHARACTERISTICS

24114 staff member
24212 some familiar with decision analysis

25 RESOURCES AVAILABLE

2512 ready computer availability
2522 strong staff
2532 decision analysis specialist
2542 high availability of decision maker
2552 high availability of assessors
2562 modest analysis budget

Table 2-2

SUMMARY CHARACTERIZATION OF THE FOREIGN POLICY DECISION SITUATION

1211 Broad options. In this case, the committee chairman could consider anything that could be done from a foreign policy standpoint to improve the energy situation in the U.S.

1222 Fuzzy options. There were many ways in which the options could be specified. For instance, the options could have been specified in terms of complete agreements, that is, they could have specified exactly what the U.S. would give up and what it would receive in return. On the other hand, the options could specify the U.S. concession and treat the return as an uncertain quantity.

1236 Many possible options. Since the task was to be responsive to the question, "What can the US do with foreign policy to get more oil?" many possible options existed. Options could have ranged between agreements and unilateral concession, two-party and multi-party options, and unidimensional and multi-dimensional options.

1241 Radical. Major departures from the existing U.S. foreign policy would need to be considered.

1252 Dynamic. A decision, once it was made, could be modified by later decisions.

13 Ease of Decision

1313 Difficult. The correct decision was not obvious to the decision maker before his problem was analyzed. (However, he did have

a rough idea of the limits of a reasonable solution.)

1322 Unfamiliar decision. The decision maker was a broad-based policy advisor; he had no previous experience in making foreign policy recommendations.

1331 Option generation was the key consideration. Since the alternatives were so broad and fuzzy, the key determinant of a good decision was the generation of good decision options.

14 Stakes

1444 It was clear from the beginning that the range of important options would have a difference in impact on the order of several hundred million dollars in the federal budget.

15 Outcome Valuation

1512 Valuation was very difficult, as many conflicting intangible valuation criteria needed to be considered.

1523 Many valuation dimensions were important. Potentially, everything of interest to the well-being of the United States in the near term and in the long term was important in this decision. These value dimensions were included, but were not necessarily limited to: volume and price of oil from the Mideastern country, balance of payments, allied goodwill, sentiments within the U.S., and oil from other countries.

1531 Approximate metric. Some of the valuation dimensions posessed natural metrics, such as oil price (dollars), and some did not, such as allied goodwill.

1541 Low combinability. The five value dimensions mentioned in 1523 above do not combine naturally.

1552 Medium timing horizon. Some of the effects of this decision could extend over about 10 years.

1563 Difficult component valuation. It was difficult to evaluate the possible outcomes on any of the valuation dimensions listed in 1523 above.

16 Outcome Uncertainty

1613 Many uncertainties affected the outcome. The impacts of the decision on the volume and price of oil, the balance of payments, allied goodwill, and sentiments in the U.S. were all uncertain. Furthermore, each of these uncertain impacts was comprised of several subsidiary uncertainties.

1621 All of the uncertainties were difficult to assess.

1632 Medium amount of uncertainty. For each of the uncertain quantities, its relative credible interval, $\frac{\text{90\% Credible Interval}}{\text{Median}}$, was between .10 and 1.00.

1641 Subsequent acts were relatively unimportant to this decision.

1653 The uncertainties lent themselves naturally to indirect judgment techniques.

1662 Medium hindsight monitoring. Some of the outcomes of the decision could be determined promptly and accurately and others could not.

2 Decision Process

21 Reaction Time

214 A recommendation was required within 60 days of when the analysis was first considered.

22 Analytic Process

2215 Several sources, including reports, experts, and the decision maker, would provide inputs to the analysis.

22212 and 22223 A group of decision analysis consultant was readily available to perform the analysis.

2230 No restrictions constrained the analysis method.

2242 The final report of the policy recommendation would have to conform to a specific format.

2252 The committee chairman was very interested in trying new analytic methods.

23 Organizational Processes

23111 This decision was initiated spontaneously in response to unanticipated developments; it was not scheduled ahead of time.

23123 The committee chairman's superior, the high-level policy maker, initiated the decision.

23213 The chairman was responsible for making a recommendation to his boss.

2331 A moderate degree of coordination was required between this decision and other foreign policy decisions.

2343 The reasons for the foreign policy recommendation would have to be justified both before and after the recommendation was made.

2352 This decision was a very controversial one.

2361 The chairman's actions were only loosely controlled.

2372 The "rational actor" model, which hypothesizes a single decision maker who relies on reasoned judgments in making his decisions, was met fairly well in this case. The policy-maker was expected to base his action on a carefully reasoned and logically consistent set of arguments treating the United States as a single entity.

2381 The United States could be considered to be slightly risk averse on all of the value dimensions.

24 Decision Maker Characteristics

24114 The decision maker, the committee chairman, was a staff member, not a line manager.

24212 The chairman had some familiarity with decision analysis.

25 Resources Available

2512 A large computer facility was readily available.

2522 A strong staff was available to work on the analysis.

2532 Decision analysis specialists were readily available.

2542 The decision maker was available on each of two half-days in each week during the analysis.

2552 Probability and value assessors were readily available throughout the analysis.

2562 Modest analysis budget. A budget of about $20,000 was available for the analysis.

3.0 CASE 2: A BUSINESS INVESTMENT DECISION

3.1 Introduction

This case refers to a decision analysis performed over a two-week period in February 1975 to analyze the decision of whether or not a six-month option on certain patent rights should be purchased. A technical description of this analysis appears in Ulvila, Brown, and Packard (1977), and it is not reproduced here.

3.1.1 Problem background - Late in 1974, the president of the AIL Division of Cutler-Hammer, Incorporated[1] discussed with an independent inventor an opportunity to invest in a new, patented flight-safety product. The potential product was related to one of the company's major areas of business although not to a current product line, in a narrowly defined sense. Applications could be to both civilian and military aircraft, but, in keeping with AIL's major business activity, only the defense market rights were considered. Because the product would be technically compatible with other AIL products, there were no concerns about the company's engineering or production capabilities.

The opportunity consisted of patent rights to this flight-safety system, limited to the defense market. A strong patent position together with superior technical performance was claimed by the inventor. Design of the product was still in the development stage, but it was developed enough to permit an evaluation of all probable

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[1] Cutler-Hammer is an electronics corporation with annual sales of about $400 million. The AIL division's annual sales are about $100 million.

costs. The inventor would make information on the design available, but AIL would have to undertake packaging for military aircraft. The immediate decision to be made was whether or not to pay $50,000 to purchase an option on these rights for a period of about six months, at which time a second decision would have to be made on a substantial prepayment against future royalties in order to support continued development. After initially satisfying himself about the possible business potential, the president of AIL assigned a small task team the responsibility of fully investigating the opportunity and developing a recommended plan of action.

One of the potential difficulties in making this decision concerned jurisdictional areas affecting flight-safety standards. These may be set variously by the Military Services and the Federal Aviation Administration (FAA). Although military aircraft must comply with many FAA rulings during peacetime, they need not comply with all of them, and they may not comply with most of them during wartime. In departing from FAA rulings, the Department of Defense (DoD) would be more likely to set more stringent standards during peacetime and less stringent ones during wartime.

In addition, the long history of flight safety is one of inaction by the FAA until a major accident forces a corrective response. Nevertheless, an FAA ruling on a relevant requirement was scheduled for the near future, but it was doubted that the FAA would make its decision according to schedule. Since the inventor wished to make the offer to other companies if AIL were not interested, he requested that the decision on the purchase of the option be made in a matter of a few weeks, a period of time clearly inadequate to resolve any of the identified uncertainties.

Not the least of these was that there were several alternative technical solutions to the flight-safety problem. Depending on the specific details of the FAA's decision, one or another of these competing solutions would be most favored. Because the inventor's particular design was controversial, there was no assurance that it would receive favorable treatment even with a secure patent position.

3.1.2 <u>Utilization of decision analysis</u> - Formal decision analysis had not been previously used at AIL to make business decisions. However, AIL's director of long-range planning was familiar with the theory and its typical applications through the literature. In addition, AIL was interested in trying these techniques on an actual decision problem in order to evaluate their worth. The decision on patent rights was considered to be an appropriate trial application of decision analysis.

The task team pursuing this objective consisted of AIL personnel who reported to the vice president for business development and analysts from Decisions and Designs, Incorporated (DDI). AIL staff provided the substantive knowledge required for the analysis and the DDI analysts provided the methodology. Throughout the two-week period of analytic effort, there was continual interaction between the key decision makers in AIL's top management and the analysts.

An initial modeling effort structured and quantified the main elements of value and uncertainty. This initial quantification slightly favored purchasing the option because of its expected value of discounted earnings. A further analysis, however indicated that this model was very sensitive to some of the values used initially. It became obviously important to analyze these values in far greater detail to develop confidence in them. Sub-modeling parts of

the analysis provided a way to gain this confidence and understanding. During the refinement process, a new, secondary valuation criterion, return on capital, was identified; but it proved to have little effect on the result. When this refined analysis was completed, it no longer supported purchasing the option.

The presentation of this analysis to the division president increased his understanding of the problem, and the discussion that arose during the presentation revealed a new alternative, waiting and seeking a sub-license. A final examination and refinement of the model indicated a slightly higher expected value for purchasing the option over waiting.

This slight difference in expected value led to a consideration of other factors. Specifically, attitude toward risk was introduced into the analysis by examining not only the expected value of the option, but also the distribution of possible values. Since the slight difference favoring the purchase of the option resulted from a high return with a low probability and was accompanied by a high probability of significant loss, the division president realized that the high-risk nature of the opportunity required special consideration. In this case, it ultimately determined the decision not to purchase the option. The alternative action of waiting resulted in lower expected and potential gain, but it also eliminated the potential loss. Thus, it became the preferred alternative.

In the final stages of the decision-making process, the analysis served as a vehicle to focus discussion on the critical issues surrounding the decision and to minimize the consideration of irrelevant issues. When the results of the analysis were presented to the president of AIL and his vice presidents for business development and operation, they

eventually agreed to reject the option, wait, and possibly seek a sub-license at a later time. This decision to wait was reached easily and unanimously, without reservation on the part of any of the participants.

3.2 Performance Determinants of a Good Analysis

In this particular case, the situation dictated that a good analysis was one that performed well in four performance categories. The analysis had to be fast, logical, inexpensive, and easy to explain.

The short time available for the analysis (S213)[2] dictated that the overall elapsed time of the analysis (P2141) was the most important measure of a good analysis. Three components of the overall analysis time were important. In decreasing order of importance, these components were that the time spent structuring the decision model had to be kept low (P2111),[3] the values and probabilities had to be assigned quickly (P2121), and the calculations in the analysis had to be performed quickly (P2131).

Because the choice of the best option was the most important consideration in this case (S1334) and the choice was a moderately difficult one (S1312), the quality of the reasoning and logic contained in the analysis (P114) was the second most important measure of a good analysis. Four components of the quality of logic, listed below in decreasing order of significance, were important. First, the analysis had to be

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[2]A complete characterization of this decision situation is presented in Section 3.5 below.

[3]The parenthetical references that are prefaced with "P" are performance measures, which are examined in Section C of Volume III.

complete in its scope (P115); it had to address the complete decision problem rather than a part of the problem, such as the assessment of probability. Second, it was important for the analysis to be conceptually complete (P111); it must take all important considerations into account and avoid serious errors of approximation. Third, it was important for the analysis method to make sound inferences from the available data (P113). Fourth, it was important for the analysis to allow the problem to be divided into manageable sub-problems (P112).

Because the stakes involved in the decision were low (S1432, S1442) and the analysis budget was low (S2561), the third most important determinant of a good analysis was its cost. The overall cost of the analysis had to be low (P2241).

Finally, because the responsibility for the decision was dispersed among a small group (S23221), the fourth important performance measure was the quality with which the decision and its supporting arguments could be communicated (P321).

3.3 Analytic Choices

The recommended analytic options for this situation are summarized on Table 3-1. The following sections explain the reasoning behind the most important recommendations and provide an indication of the order in which the analytic choices might be made. Although the discussion below is meant to be self-explanatory, the reader may wish to refer to Section 3 of Volume III for a more detailed description of the range of analytic choices that were available.

3.3.1 Choice of the amount of analysis - Guidelines of situational characteristics that favor using decision analysis are presented in Section 3.1.2 of Volume I. This case can be characterized along these situational dimensions as follows.

1 USER'S OPTIONS

11 USE DECISION ANALYSIS AT ALL?

112 use decision analysis

12 DOLLAR AMOUNT OF ANALYSIS

121 small amount of analysis

13 ROLE OF DECISION ANALYSIS

1311 private aid
1322 optional decision
1332 current decision
1342 display
1351 communication

14 ORGANIZATION

1419 consultants performed the analysis
1423 experts provided inputs
1431 close relationship with decision process

15 RESOURCES

1511 decision-analytic expert
1521 computer

2 MODEL APPROACH OPTIONS

21 COMPLEXITY OF ANALYSIS

211 simple

22 COMPREHENSIVE /PARTIAL ANALYSIS

221 comprehensive

23 DEGREE OF APPROXIMATION

233 exact

3 INPUT STRUCTURE

31 UNCERTAINTY

3112 complete probability distributions
3122 medium time horizon
3132 act modeled as an event
3142 medium level of detail
3151 low grouping of uncertain quantities

32 VALUE

3221 modest decomposition
32319 aggregation

4 INPUT SPECIFICATION

41 DECISION OPTIONS

4111 real option

42 EVENTS

422 specific

43 VALUE CRITERIA

4311 natural units
4322 floating-zero base
4331 present value and
4333 time flow

44 INDIRECT ASSESSMENTS

4411 few conditioning tiers
4431 decomposed assessment model

45 ELICITATION TECHNIQUE

4512 direct elicitation of discrete probabilities
4521 fractile elicitation of continuous probabilities

5 OUTPUT

51 SPECIFICATION

5131 value distributions

52 DISPLAY FORMAT

5211 graphic display

53 ANALYTIC DEVICES

5391 grouping

6 MODEL MANAGEMENT

61532 a moderate amount of sensitivity analysis on both values and probabilities

Table 3-1

SUMMARY OF AIL ANALYSIS CHOICES

Important factors favoring a large amount of analysis:

- The options were clearly defined (S1221).
- Choice was the key consideration (S1334).
- This analysis was considered a "trial run" of decision analysis, and it might determine whether decision analysis would be used in the future (S2252).
- The decision maker was somewhat familiar with decision analysis (S24211).

Important factors against a large amount of analysis:

- The choice was not a very difficult one (S1312).
- The stakes were low (S1421, S1432, S1442).
- Few input sources needed to be considered (S2211 or S2212).
- The decision maker did not need to justify his decision to others (S2340).

Other factors favoring decision analysis:

- The decision was a current one (S1111).
- The "rational actor" model, which hypothesizes a single decision maker who relies on reasoned judgments in making his decisions, fits very well in this case (S2372).
- A large computer facility was readily available (S2512).
- A strong staff was available (S2522).

Other factors against decision analysis:

- The choice was not expected to recur (S1122).

- Outcomes could be easily evaluated (S1510).
- A decision was required in a few days (S213).
- The decision maker could spend only a little time on the analysis (S2532).
- Only a small budget was available for the analysis (S2561).

More factors argued against using decision analysis in this case than argued for it. However, the fact that the proposed decision analysis would serve as a "trial run" to determine whether or not decision analysis would be used for future decisions was a very strong argument in favor of the analysis. In addition, certain of the favorable situation characteristics tended to negate some of the unfavorable ones. For example, because the options were clear, the decision maker was somewhat familiar with decision analysis; and because a strong staff was available, an analysis could be made relatively quickly and inexpensively. Thus, the importance of a short reaction time and a small analysis budget was reduced. Overall, then, some analysis was justified (A112).

The two situation characteristics that were the most important determinants of the amount of analysis were the stakes and the size of the analysis budget. In this case, both the stakes and analysis budget were small, and thus only a small decision analysis was indicated (A121).

3.3.2 Type of analysis - The choice of whether to do decision analysis at all and the general level that such an analysis should take are decisions that can be made, for the most part, by the decision maker without involving the decision analyst. The choice of the type of analysis to use, however, requires the judgment of the analyst as well as that of the decision maker. In this case, analytic choices were made at roughly four points in the analysis: before formal modeling

commenced, during the initial modeling effort, during the final modeling effort, and immediately preceding the presentation. (Please note that the discussion below is more complete, covering more analytic choices, than similar discussions in the other case studies.)

Before formal modeling - At the first point of analytic choice, before formal modeling commenced, the decision maker and the analyst both affected the choice of analytic options. Five major analytic choices were made at this time. First, the decision maker chose to use decision analysis consultants in a close working relationship with AIL staff members. Second, the decision maker and analyst decided to model the problem from the personal point of view of the decision maker and to emphasize the display of the analysis. Third, the analysts decided to build a simple but comprehensive model of the decision problem and to refine the model's structure on the basis of a sensitivity analysis. Fourth, the decision maker and analyst decided to use the judgments of AIL staff members as inputs to the model. Fifth, the analyst decided to use a computer to perform the calculations in the model.

Decision analysis consultants were indicated for this analysis (A1419, A1511) because AIL had no previous experience using decision analysis, it did not have a well-developed in-house decision analysis capability (S24212), and decision analysis consultants were readily available (S2532). The close working relationship between the decision makers and the AIL staff members (A1431) is a relationship that we recommend in general. We only recommend against this relationship when the decision is a small, repetitive one which does not require much judgment on the part of the decision maker.

The decision to model the problem from the decision maker's (division president's) point of view rather than from

an institution's (Cutler-Hammer's) point of view (A1312) was made so that the analysis would conform to the decision maker's motivation. In addition, a model that is built to resemble the decision maker's personal perception of the problem closely is more likely to yield a decision that will guide his action than one that is not. The decision to emphasize the display aspect of the analysis (A1342), rather than the optimization aspect, is one that we recommend in general. This choice was particularly important in this case because several people shared the responsibility for various aspects of the analysis (S23221). In such a case, the communication of the reasons surrounding the choice of a decision option is very important (P321), and an emphasis on the display of the analysis promotes such communication.

Because the speed (P2151), logic (P114), cost (P2241), and communication (P321) of the analysis were so important, a simple but comprehensive model was indicated. A simple (A211) model can usually be built quickly and inexpensively, and it facilitates communication. However, such a model needed to be comprehensive (A221), encompassing nearly all relevant considerations, in order to yield the completeness (P111) necessary for a logical choice. In this particular case, a simple yet comprehensive analysis was possible because the options under consideration were clearly and narrowly defined (S1221, S1212), the value dimensions were few and easy to assess (S1522, S1561), and the uncertainties were moderately easy to assess (S1622). Refining the analysis based on the results of a sensitivity analysis (A6153) was the fastest and most economical way to ensure that the final model would be the best one that was possible within the time available for the analysis.

AIL staff members were the only sources used to provide judgments on the inputs (A1423) of values and probabilities because they were the best sources available within the time limit.

Finally, a computer program was written specifically for this problem (A15212) because this was the only way that the sensitivity of the decision to the model's inputs could be examined quickly. Furthermore, because the initial model did not contain a large decision tree structure and did not use complicated probability distributions, but did require an expected present value calculation, it was easier to write a FORTRAN program for this model than to use any of the available pre-packaged decision analysis programs.

During initial modeling - During initial modeling most of the analytic choices were made by the analyst. The most important analytic choices made at this time, as explained below, concerned the time horizon, the valuation criteria, and the model of the event structure.

A 10-year time horizon (A3122) was indicated for the model because the effects of the immediate decision were expected to extend over this length of time (S1552). Furthermore, these effects were easy to identify, assess, and model.

The decision maker indicated that the earnings flows and return on capital (ROC) flows over the 10-year time horizon were the most important criteria in making his decision. These criteria were most easily understood and assessed in their natural units (A4311), dollars for earnings and percent for ROC. In addition to these natural units, a "floating-zero" base (A4322), which evaluates all outcomes relative to those resulting from the choice of a particular alternative (in this case, the alternative "do not purchase the option"), was also appropriate in this case. The floating zero base was indicated mainly because the alternative of not purchasing the option ("business as usual") was a convenient benchmark for comparison. In addition, this project was not big enough (S1432) to substantially influence a large part of a relevant

absolute or "fixed-zero" scale such as the AIL division's total earnings.

Flows over time are often difficult for the decision maker to compare directly, thus we generally recommend the use of summary measures instead of flows over time whenever such summary measures are available. In this case, the earnings flows over time combine naturally into a present value by using a discount factor (S1543). In addition, it was AIL's convention to evaluate projects such as this on the basis of the present value of their pre-tax earnings, discounted at 20% per annum (S2239). These situations indicated that the earnings flows should be aggregated into a single present value figure (A32319, A4331). On the contrary, such a convenient aggregation method does not exist for the ROC flows. Furthermore, ROC flows do not combine naturally with earnings flows (for one thing dollars do not combine naturally with percentages). Thus, aggregations of the ROC flows into a single figure and ROC flows with earnings flows were not indicated.

While we eventually determined that several uncertainties were important, we initially sought to maintain the analysis at a very simple level (A211). Thus, only very few events should have been modeled in the early analysis. The subsequent act of whether or not to exercise the option and enter into a license agreement with the inventor was among the items that were included in the early analysis. However, we recommended that this subsequent act be treated, in the model, as an uncertain event, rather than as an act (A3132). There were two reasons for this recommendation. First, this subsequent act was critical to the outcome of the initial decision to purchase the option (S164). Thus the subsequent act deserved some explicit modeling. Second, this initial decision would result in a complex information search. In this case it was convenient to avoid modeling explicitly the information that

might be received by treating the subsequent action as an uncertain event.

<u>During final modeling</u> -. Analytic choices during the final modeling were made by the analysts. At this stage in the analysis, the most important analytic choice concerned the direction in which the analysis should be refined. Two main alternative refinements were available. The event and earnings distributions could be modeled in more detail or the ROC valuation criterion could be investigated in greater detail. The results of a sensitivity analysis (A61532) indicated that a refinement of the probability distributions of events and earnings would significantly increase the logic of the analysis for only a small investment of time and effort. On the other hand, a cursory investigation indicated that a refinement of the ROC valuation criterion would only slightly increase the logic of the analysis but would require a large investment of time and effort. Thus, refinements in the models of the events and earnings were indicated. In particular, the sensitivity analysis indicated that the decision was most sensitive to the probability of winning a contract and the size of the contract, and thus these were the events whose models should be refined.

The probability of receiving a contract was the most difficult probability to determine because it depended on four things: whether a plane crash would occur in the near future, when Congress or the FAA would mandate a flight-safety system, whether the mandate would include certain standards, and whether tough competition would develop. Since the dependence relationship among these four events was so clear (S1653) and each event was so easy to assess (S1622), the analyst could quickly, accurately, and inexpensively model the probability of receiving a contract in a conditioned assessment model that contained the four tiers of events (A4411, A3151).

In the initial model, the earnings flows were obtained by direct judgment. However, the assessors found it easier to think about earnings if they decomposed their assessment into three components, the number of units, the price per unit, and the earnings as a percentage of sales revenue (S1653). Thus, a decomposed assessment model (A3221) was the best way to refine the earnings model. In this model, a continuous distribution was assessed for each of the three components of earnings using the fractile method (A4521). Although this assessment method generally provides very accurate assessments, it seldom yields distributions that have analytical forms, such as normal distributions. Thus, the assessed distributions needed to be modified before they could be incorporated into the analysis. Since little time was available for the analysis (S213), the distributions were simplified into three-event representations (A5391) using the procedure explained on page 189 of Brown, Kahr, and Peterson (1974). In addition, it appeared that a special-purpose computer program, TREE, should be used to perform the calculations on the earnings distributions (A15211). At the time, it appeared that this computer program, which interactively elicits a decision tree and then automatically processes the tree and presents a distribution of values, could provide the needed calculations more quickly and accurately than the analyst could do manually. However, in retrospect it appears that an analyst could have done a more efficient job of calculation than the computer did; thus, this computer program should not have been used.

<u>Prior to Presentation</u> - Immediately prior to the presentation of the analysis, both the decision maker and the analyst helped determine the proper display of the analysis. This display contained two important elements; a value distribution was presented for each decision option and graphic displays were used throughout the presentation.

A value distribution for each decision option displayed the risk inherent in the decision. Since the risk aversion of the decision maker (S2381) ultimately became the deciding factor of the analysis, an incorporation of risk was very important to the analysis. Because the decision maker had only some familiarity with decision analysis (S24211) and because the amount of analysis time was small (S213) and the communication of the analysis was important (A1351), a closed-form utility analysis was not indicated. However, the display of a risk profile of each decision option (A5131) was indicated, for the reasons above and because the risk profile clearly highlighted the difference between the two options. Specifically, one option offered, in present-valued earnings, an expected value of $100,000, a large chance of a loss of $50,000 to $200,000, and a small chance of a gain of $5.25 million, while the other option offered an expected value of $50,000, virtually no chance of a loss, and a small chance at a gain of $800,000.

A graphic display of the results of the analysis was important because the model incorporated time flows (A4333) and a risk profile (A5131), both of which are best displayed graphically. In addition, the graphic display promoted the communication of the reasons for the decision (A1351) by showing how the various events, especially in the conditioned assessment (A4411), interacted.

3.4 Conclusions

The primary motivating objective for developing the taxonomies of performance measures, analytic options, and situations is to enable a decision maker and an inexperienced analyst to make the types of analytic choices described in Section 3 more easily. It is not clear that the present development of the taxonomies meet this objective completely.

The taxonomic framework seems to serve well the purpose of aiding in the broad choices of whether or not to use decision analysis and how much analysis to use. For these choices, the decision maker can easily use the taxonomies by characterizing his decision situation along the primary and secondary dimensions listed in Section 3.3.1 and by examining the degree to which his situation indicates that a large amount of analysis should be used.

However, the taxonomic framework does not appear to be as helpful for making more detailed analytic choices, such as the choice, explained in Section 3.3.1 above, of how to refine a simple initial analysis. For such choices, it is possible for an analyst to force his reasons for making a choice into the framework of the taxonomy, but it is not straightforward for him to do so. Because such reasoning is tricky to fit into the taxonomic framework, the value of the taxonomy for making these choices is not clearly evident.

3.5 Appendix: Situation Characterization

Section 3.3 above explaines the major analytic choices that needed to be made in this case. This section presents a more complete and formal characterization of the situation in terms of the Situation Taxonomy that is specified and defined in Section A of Volume III. Table 3-2 summarizes this characterization and the following discussion illustrates each element of the characterization in terms of specific instances in the case.

1 Decision Substance

11 Basic Situation

1 DECISION SUBSTANCE

11 BASIC SITUATION

1111 current choice
1122 one expected occurrence
1131 operating act

12 OPTIONS

1212 narrow
1221 clear
1231 two
1241 adaptive
1251 static

13 EASE OF DECISION

1312 moderately difficult
1321 familiar to the decision maker
1334 choice is key consideration

14 STAKES

1421 low cost swing
1432 few million $ value swing
1442 few hundred thousand $ option impact

15 OUTCOME VALUATION

1510 easy net valuation
1522 low no. of value dimensions
1532 exact metrics
1543 high natural combinability
1552 medium time horizon
1561 easy component valuation

16 OUTCOME UNCERTAINTY

1613 many uncertainties
1622 moderately assessable
1632 medium amount of uncertainty
1643 important subsequent act
1653 lends itself to indirect techniques
1661 low hindsight monitoring

2 DECISION PROCESS

21 REACTION TIME

213 days

22 ANALYTIC PROCESSES

2211/2 few input sources
22212 group of decision
22223 analysis consultants
2231 few restrictions on the analytic method
2240 no restrictions on the reporting procedure
2252 "trial run" analysis

23 ORGANIZATIONAL PROCESSES

23111 spontaneous initiation
23121 initiated by decision maker
23221 a small group shared responsibility for the decision
2330 no coordination
2340 no justification
2350 uncontroversial
2361 loose performance control of the decision maker
2372 rational actor model
2381 risk averse

24 DECISION MAKER CHARACTERISTICS

24113 high level authority
24211 little familarity with decision analysis

25 RESOURCES AVAILABLE

2512 computer readily available
2522 strong staff
2532 decision analysis specialist
2541 little decision maker availability
25512 high availability of assessors
25522 high sophistication of answers
2561 small analysis budget

Table 3-2

SUMMARY CHARACTERIZATION OF AIL SITUATION

1111 Current choice. The problem was to decide immediately whether or not to purchase the option.

1122 The decision was expected to be made only once.

1131 Operating act. The action was whether or not to purchase the option, not whether to seek information about the opportunity.

12 Options.

1212 Narrow options. The options were defined narrowly as whether or not to buy the option on the patent license.

1221 Clear options. The options were to pay the inventor $50,000 for the 6-month option or not.

1231 Only two options were available.

1241 Adaptive. The options were not a major departure from AIL's normal operations.

1251 Static. The decision to be made could not be modified later. That is, this decision would be made final.

13 Ease of Decision

1312 Moderately difficult. The correct decision was not obvious to the decision maker before the analysis was done.

1321 A very familiar type of decision. The division president made these kinds of decisions very often.

1334 Choice was the key consideration; it was more important than inference or valuation.

14 Stakes

1421 Low-cost swing. The most expensive alternative cost $50,000, and the least expensive cost nothing.

1432 Before the analysis was made, AIL personnel judged that the difference between the best outcome, winning a large contract, and the worst one, investing in promotion and development and receiving no contract, was on the order of several million dollars in present valued (PV) earnings.

1442 Before the analysis, the expected difference in value between the two decision options was of the order of $100,000 in PV earnings.

15 Outcome Valuation

1510 Easy outcome valuation. When the uncertainties are resolved, earnings and return-on-capital (ROC) would be readily identifiable for this product, and these two summary value measures sufficiently described the attractiveness of the outcome to the decision maker.

1522 A low number of value dimensions were important. The earnings flows and returns on capital (ROC) in each of ten years were important to the decision maker.

1532 Exact metric. The value dimensions were easily measured in dollars (for earnings) and percent (for ROC).

1543 High natural combinability. Although the return on capital flows neither aggregate naturally into a single figure nor combine naturally with the earnings flows, the earnings flows combine very naturally into a single present-value figure. On the whole, we consider this to be a high degree of natural combinability.

1552 Medium time horizon. The effects of the decision could extend over 10 years.

1561 Overall, the component valuation was very easy. However, the return on capital valuation was a bit more difficult than the earnings valuation.

16 Outcome Uncertainty

1613 Many uncertain quantities influenced the decision. These included:

A. Would the option, if purchased, be exercised?

B. What was the probability of receiving a contract?

1. When would a legislative or FAA mandate occur?

a. Would a plane crash occur in the near future?

b. Would the mandate contain the needed specific standards?

2. Would tough competition develop?

C. What earnings would result from the contract?

1. How many units could be sold?

2. What price could be obtained per unit?

3. What profit margin would result?

4. Would AIL win a bid for the entire contract or just part of it?

1622 Medium assessability. It was moderately difficult to determine the appropriate probability distributions of the uncertain quantities.

1632 Medium amount of uncertainty. The relative credible intervals, $\frac{\text{90\% Credible Interval}}{\text{Median}}$, of all distributions were between .10 and 1.00.

1643 The subsequent act of whether or not the option would be exercised critically affected the outcome.

1653 The uncertainties in the case lent themselves naturally to indirect judgment techniques. The probability of a contract was easily thought of in terms of conditioning events, and the contract's earnings were easily decomposed into their constituent parts (see 1613 above).

1661 Low hindsight monitoring. The total outcome of the decision could not be known for about 10 years.

2 Decision Processes

21 Reaction Time

213 Days of Reaction Time. A commitment of funds--paying a $50,000 license fee--was required within two weeks of when the decision analysis was first considered.

22 Analytic Processes

2211 or 2212 At most, a total of two or three sources were available to provide all inputs (values and probabilities).

22212 and 22223 A group of decision analysis consultants were readily available to perform the analysis.

2231 It was AIL's convention to use the present value of pretax earnings, discounted at 20%, to evaluate projects like this one.

2240 No restrictions constrained the reporting procedure.

2252 "Trial run" analysis. This decision was chosen as a trial application of decision analysis, in part to help determine the usefulness of decision analysis for other of AIL's decisions.

23 Organizational Processes

23111 This analysis was initiated spontaneously in response to an unanticipated opportunity.

23121 The decision was initiated by AIL's division president, the decision maker.

23211 The user of decision analysis, the division president, is also the person who will make the decision.

23221 A small group, consisting of the division president, the vice presidents for operations and business development, and the director of long-range planning, shared the responsibility of investigating this opportunity and making a decision on it.

2330 This decision did not need to coordinate with other decisions.

2340 The division president did not need to justify his decisions.

2350 This was not a controversial decision.

2361 Loose performance control. The division president is accountable for his division's results to the corporate headquarters, mainly through periodic reports of the division's profits.

2372 The rational actor model, which hypothesizes a single decision maker who relies on reasoned judgments in making his decisions, is met very well in this case. There is a single decision

maker, the division president, who will make his decision based on a reasoned judgment.

2381 The organization was slightly risk averse.

24 Decision Maker Characteristics

24113 High-level authority. The division president was the chief executive of the division.

24211 Little familiarity with decision analysis. The decision maker had some familiarity with decision analysis as well as with other quantitative methods.

25 Resources Available

2512 A large computer facility that contained special-purpose decision analysis programs (Harvard's MANECON and SRI's TREE and CTREE) was available in a time-sharing mode.

2522 A strong staff was available, including the director of long-range planning, who was familiar with decision analysis and with the substantive issues of this decision problem.

2532 Decision analysis specialists were readily available.

2541 Little decision-maker availability. The decision maker was available for a half-day briefing at the end of a two-week analysis period.

25512 High availability of assessors. The probability and value assessors were available

for daily involvements with the analysis, each involvement lasting several hours.

25522 The staff members who were also the assessors were familiar with decision analysis.

4.0 CASE 3: A DESIGN-TO-COST EVALUATION

4.1 Introduction

This case refers to a decision analysis performed by Decisions and Designs, Incorporated for the Naval Electronic Systems Command (NAVELEX) to evaluate alternative design proposals for an Electronic Warfare (EW) system. A technical description of this analysis is contained in Hays, O'Connor, and Peterson (1975), and much of the following description is excerpted from that document.

4.1.1 Problem background: The design-to-cost concept - Faced with increasing costs and tightening budgets in the procurement of major military systems, the Department of Defense (DoD) promulgated a new procurement policy in 1971 linking designed performance and its attendant benefits to cost ceilings. This policy, which was enunciated in DoD Directive 5000.1 and subsequently implemented by means of instructions published by each of the Military services, stated that:

> discrete cost elements (e.g., unit production costs, operating and support cost) shall be translated into 'design to' requirements. System development shall be continuously evaluated against these requirements with the same rigor as that applied to technical requirements. Practical tradeoffs shall be made between system capability, cost, and schedule. Traceability of estimates and costing factors, including those for economic escalation, shall be maintained.[1]

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[1] Acquisition of Major Defense Systems, DoD Directive 5000.1, July 13, 1971.

The intent of this policy statement was to emphasize the need to balance (by means of an interactive design process) military costs and management with the quantities required to achieve the most effective military capability with available DoD resources.

The design-to-cost concept introduced by DoD Directive 5000.1 has recently been superceded by DoD Directive 5000.28, which further states that:

> The Design to Cost concept establishes cost as a design parameter during a system's design and development phase and provides a cost discipline to be used throughout the acquisition and operation of a system.[2]

Changes in procurement policies obviously involve new procurement practices and require new responses in system design. Design-to-performance and design-to-cost procurement policies both relate performance and cost, but each does so differently, by placing different emphasis upon one or the other. Since their impact upon system design is also different, an understanding of the differences between the two kinds of procurement policies as they affect system design encompasses the reasons for the change and suggests means of adapting to it.

Under a design-to-performance procurement policy, performance requirements in the RFP are stated as absolute descriptions of needs. Any system failing to meet the stipulated requirements is defined as essentially worthless. If, for example, the requirement that a military system respond within ten minutes to a distant threat were taken literally,

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[2] Design to Cost, DoD Directive 5000.28, May 23, 1975.

a system that responded in ten-and-one-half minutes would be regarded as worthless. However, in most cases, such a system would not be worthless, only worth less than a system actually satisfying the requirement. Taken literally, such a requirement implies a price-is-no-object attitude toward design because the technology necessary to satisfy the requirement may be exremely expensive. Although seldom reflected in practice, such an attitude is implicit in performance requirements and can lead to over-designed systems. Since over-design is as much an economic as an engineering concept, a design-to-performance procurement policy may over-emphasize performance and lead to cost overruns, reduced acquisition, or compensatory sacrifices in operational performance elsewhere in the system.

Under a design-to-cost procurement policy, these problems may be reduced or eliminated. Rather than stating absolute performance requirements, the policy stipulates a production cost ceiling for each unit of the system and allows the levels of performance to vary within certain limits. These variable levels of performance are suitably valued across that range. Accordingly, since the design of a system requires the maximum value of performance within a budgetary constraint, over-design is less likely, military value is maximized, and the risks of cost overruns, insufficient acquisitions, and compensatory sacrifices in operational performance are minimized in most cases. (Although there is some controversy whether or not more modest levels of performance dictated by cost-per-unit ceilings will be sufficient for most mission requirements in certain special cases, this is not an issue addressed in this case.)

For a contractor, the most immediate implications involve his responsibilities for a new system. Previously, when a Military Service defined the technical requirements of

a system, the contractor's primary responsibility, theoretically, was to propose a system design meeting those requirements. He also attempted to determine a means of producing the proposed system within minimum production standards of quality at a cost lower than that of a competitor. Presently, since a Military Service simply outlines the mission requirements of a system in rather general terms and states the production cost-per-unit ceiling, and since all contractors have the same production ceilings and standards to meet, their primary responsibility is to propose a system design offering more and efficient technical advantages, not lower cost, than does a system design developed by a competitor.

In practice, the design-to-cost procurement policy is governed by three dominant considerations: the probability of meeting production and installation schedules, the acceptability of development and acquisition costs, and military worth.

First, after issuing a Request for Proposal (RFP) and receiving proposals in reply, the Military Service must estimate the likelihood that each contractor can meet the production and installation schedules, were his proposal accepted. This estimate is based upon assessments of, among other considerations, the contractor's past performance in fulfilling government contracts and his capabilities to produce the proposed system along with his other, possibly unrelated, production commitments.

Second, the Military Service must judge the expense required to develop a working prototype for testing. Since the burden of designing a system under design-to-cost procurement policies falls largely upon each contractor, the Military Service has paid selected contractors to develop their proposals.

Third (and of major concern in this case study), the Military Service must evaluate the military worth of a contractor's design proposal and compare that proposal with other, often quite different, proposals. For implicit in design-to-cost procurement policies is a tacit reliance upon the ingenuity of each contractor to achieve maximum value for a stipulated cost. The flexibility permitted by the absence of specific technical requirements allows each contractor to develop a proposal which appears to him to best meet the requirements of a given system. Since flexibility allows diversity--each contractor develops a design that reflects his particular corporate interests, his understanding of the mission, and his technical and manufacturing capabilities--some method of evaluating system design proposals that may be quite different from each other is required.

4.1.2 Decision setting - Under this general directive within the DoD to use the design-to-cost procurement policy, the Naval Electronics Systems Command (NAVELEX) was faced with a procurement decision for an Electronic Warfare (EW) system, a group of sophisticated and complex semi-automated, computerized suites for detecting and responding to different threats to naval surface vessels in various situations. In particular, NAVELEX had to choose to fund two contractors from among six who responded to the RFP to develop their systems from the design stage to the prototype stage.

The decision process for choosing the two contractors was fairly complicated. Ultimately, the decision would be made by NAVELEX's source selection authority (SSA). His decision, however, would be influenced heavily by a recommendation that he would receive from the source selection advisory council (SSAC) that was formed to evaluate the proposals. The SSAC, in turn, would base its recommendation on

evaluations of the proposals that it would receive from the source selection advisory board (SSAB).

At the point when decision analysis was first considered in this case, the project manager, who headed the SSAB, was faced with the task of ensuring that the SSAB had its evaluations completed within six weeks. He also had to ensure that the evaluations reflected the judgments of several EW experts. He further had to be sure that his evaluations could be justified both up the line of authority to the SSAC and the SSA and to the contractors. This justification to the contractors was especially important because a contractor who was justly dissatisfied with his system's evaluation could formally protest the evaluation and thereby slow down the whole procurement process.

Although the design-to-cost policies have been in effect since 1971, their previous implementation was limited to systems already beyond the design and development stage and ensured only that the system would be produced within previously budgeted limits. This evaluation of the Navy's EW System was thus the first time that design-to-cost procurement policies had been implemented from the very initiation of a program to procure a major military system. It also marked the first time that decision-analytic techniques were considered for evaluating proposals in the military procurement process.

Thus, because this was the first time that these methods were used, the contemplated analysis would, in part, determine the future use of both the design-to-cost policy and decision analysis techniques for military procurement decisions.

4.2 Performance Determinants of a Good Analysis

This case required three major types of performance. The analysis had to communicate the reasoning surrounding the evaluations (P321),[3] effectively disaggregate the valuation (P112), and promote the management of existing expertise (P122). In addition, the analysis had to be completed within six weeks time (P21) and within its budget (P22).

Effective communication was very important in this case because the evaluations were very controversial (S2352)[4] and required a substantial amount of justification (S2343). The communication of reasoning surrounding the evaluations was particularly important because a contractor could protest an evaluation that he considered unfair, and this protest would add greatly to the costliness of the EW system (P22).

A large amount of data concerning the valuation of the proposals was available at the beginning of the case. Thus, a good analysis would have to use the existing data effectively (P122). Finally, because the overall valuation was very difficult (S1512) but lent itself naturally to indirect judgment (S1654), an important feature of the analysis was how well it disaggregated the problem into manageable sub-problems (P112).

4.3 Analytic Choices

Some of the analytic options that we recommend for this case are summarized in Table 4-1. The following sections

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[3]References that begin with the letter "P" are performance measures, which are explained in detail in Section C of Volume III.

[4]References that begin with the letter "S" are situation characteristics, which are explained in Section 4.5 below.

1 USER'S OPTIONS

11 USE DECISION ANALYSIS AT ALL?

112 yes

12 DOLLAR AMOUNT OF DECISION ANALYSIS

122 medium

13 ROLE OF DECISION ANALYSIS

1312 public
1342 display
1351 communication

14 ORGANIZATION

1419 consultants to perform the analysis
1423 experts provide inputs

15 RESOURCES

1511 decision analysis specialists

2 MODEL APPROACH OPTIONS

21 COMPLEXITY OF ANALYSIS

212 moderately complex

24 BALANCE OF EFFORT

2411 low effort on modeling options
24211 low effort on modeling uncertainty
24223 high effort on modeling value

3 INPUT STRUCTURE

31 UNCERTAINTY

3110 mostly certainty equivalents
3141 little detail

34 VALUE

3212 medium comprehensiveness
3222 substantially decomposed
32312 single utility index
32411 linear value function

4 INPUT SPECIFICATION

42 EVENTS

421 scenarios

43 VALUE CRITERIA

4319 mixture of units
4322 "floating zero" base

45 ELICITATION TECHNIQUE

4512 direct for probabilities
4532 direct for values

5 OUTPUT

51 SPECIFICATION

5121 single value for each option

6 MODEL MANAGEMENT

61533 many iterations on both value and probability assignments

Table 4-1

MAJOR ANALYTIC CHOICES IN THE DESIGN-TO-COST CASE

explain the reasoning behind the most important of these choices.

4.3.1 Choice of the amount of analysis - Section 3.1.2 of Volume I contains an explanation of the guidelines for determining the proper amount of decision analysis in terms of situational characteristics. This case can be characterized along these situational dimensions as follows.

Important factors favoring a large amount of decision analysis:

- The choice in this case, the evaluation of the various proposals, was difficult (S1313). No proposed system was obviously superior or inferior to the others.

- The key determinant of a good analysis was how well it provided the SSAC with the complicated evaluation information that it needed in order to make a recommendation (S1332).

- The stakes involved in this decision were fairly high (S1443). A wrong decision could cost the Navy on the order of $10 million.

- The opinions of several experts were important for this evaluation (S2215).

- The evaluations required extensive justification both within the Navy and to outside contractors (S2342).

Important factors against a large amount of decision analysis:

- The project manager was unfamiliar with the techniques of decision analysis (S24210).

Other factors favoring a large decision analysis:

- This was a current choice (S1111), as existing proposals were being evaluated.

- The choice was expected to recur (S1124). A similar model would be needed at a later time to evaluate the two systems that were retained for prototype development.

- The evaluation of the proposals was difficult (S1512).

- The evaluations were required in six weeks (S214).

- The "rational actor" model, which hypothesizes a single decision maker who makes his decisions on the basis of reasoned judgments, was a close approximation to this decision making process (S2372).

Other factors against a large analysis:

- The uncertainties were easy to assess (S1623).

- A modest budget was available for the analysis (S2562).

This characterization indicates that a large analysis should have been used in this case. Most importantly, the stakes involved in the decision were large, and the evaluations had to be justified to a large audience. In such a case, a large sensitivity analysis is a very valuable part of a good analysis. However, a modest budget of about $20,000

was available. Our recommendation is that about $20,000 more would have been justified in this case.

4.3.2 Type of analysis - The following major choices were made mainly by the analysts during the course of the analytic effort. These choices were in the areas of the overall modeling strategy, the modeling of value, and the modeling of uncertainty.

Overall modeling strategy - The analysts made five major choices about the overall strategy of the modeling effort. These included the decision to perform the analysis from the viewpoint of a public institution, to emphasize the display and communication aspects of the aid, to devote most of the effort to modeling value, to perform only a modest amount of input iteration, and to rely on two experts to provide most of the model's inputs.

The choice to build the decision model for the U.S. Navy's benefit (A1312) rather than for the personal benefit of the project manager was made for basically the same reason that a similar decision was made in the Foreign Policy Decision Case (Section 2.0 above). Specifically, the project manager was motivated to evaluate the proposed EW systems from the point of view of the systems' values to the Navy. In this case, it was especially important for the analysis to serve a public function because the evaluations would have to be justified and defended to the EW project's SSAC before a decision would be made on which contractors to retain (S2342).

The model was used to display and communicate the reasoning surrounding the evaluations because the evaluations required so much justification (A1342). In fact, we feel that more attention should have been paid to the communication aspects of this analysis than was actually done. Specifically,

more attention should have been paid to recording and displaying the rationale for choosing certain analytic techniques, such as multiplicative combinations of values, and to identifying and highlighting the key points that controlled the evaluations. If the analysts had paid greater attention to these details of communications, the analysis would have been much more valuable to the project manager. In particular, including more rationale would have spared the project manager the task of explaining every detail of the analysis to the SSAC and would have allowed him to focus their attention on the key substantive issues rather than the more trivial technical ones. The point is that a very precise model is of little value if its reasoning cannot be communicated effectively. Thus, we generally recommend that an evaluation model such as the one developed in this case be accompanied by a large amount of explanation.

Most of the analytic effort was devoted to modeling value (A24223), and little effort was spent defining the options (A2411) or modeling the uncertainties (A24211). Since the key function of analysis was to provide the SSAC with evaluations of the proposals (S1332) and since the valuation was difficult (S1512) and needed to consider many complicated factors (S1523), it was natural to devote a large amount of effort to modeling the valuation. In addition, the options were clearly defined by the six contractors' proposals (S1221), and the uncertainties were both relatively unimportant and fairly easy to assess (S1623). Thus, little of the analysis effort was required in order to model the uncertainties adequately. In general, we recommend this distribution of effort, with the main emphasis on valuation, when the main purpose of the analysis is valuation.

In the actual analysis, checks were made on the validity of the value assessment using two methods. The first checks were made by comparing the model's initial structure

and input assessments with the judgments of several groups of experts. The second checks were made by using the model to evaluate existing EW systems and comparing the model's valuations against the intuitive valuations of experts who were very familiar with the existing systems. This ensured that the model behaved in accordance with the generally accepted assessments of the existing technology. On the basis of these checks, the model was refined to improve its external validity. These kinds of checks are ones that we generally recommend.

Different kinds of checks are also, in general, appropriate, but they were not used extensively in the actual analysis. These are checks of the model's internal validity. Such checks are attained by varying the probabilities of uncertain events (the scenarios) and the importance weights of valuation components, noting the resulting changes in the valuation of the different systems. Such checks both identify the critical aspects of the model and determine the robustness of the model. In deference to the analysts in this case, such checks of internal validity are difficult and very time consuming unless a computer is used to perform the required calculations. In this case a computer was not readily available (S2510). This condition suggests that in cases where a large evaluation effort is anticipated, steps should be taken early in the analysis effort to obtain access to a computer facility if such a facility is not otherwise readily available.[5]

To re-phrase the above analytic choice in the terms of the taxonomy, a modest amount of iteration was

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[5] Since the time that this analysis was performed, Decisions and Designs, Inc. has developed computer programs specifically designed to perform these types of sensitivity checks on this type of model. These programs can be used on the IBM 5100 portable computer.

performed on the value inputs to the model (A61512) but a large amount of iteration for both the value inputs and the probability inputs is recommended (A61533).

The final choice on overall modeling strategy was to use two EW experts from the Naval Research Laboratories (NRL) as the primary sources of inputs for the model. This choice was made because these experts were available to devote much time to the analysis (S2552) and because they were familiar with the other people who could provide the required information in other areas of expertise.

Modeling of value - The analysts made three major choices about the modeling of value. These choices were to seek a value measure that would be moderately comprehensive, to decompose the value measure substantially, and to utilize "swing weights" for the value assessments.

Although three main categories of value were important for the evaluation of the proposals (military worth, cost, and management), only one of these, military worth, was very difficult to evaluate. Furthermore, military worth was composed of eight elements, only one of which, the technical system utility (TSU), was difficult to determine. That is, other elements of military worth, such as the degree of modularity of a proposed system, could be determined readily by direct observation. However, a proposal's TSU could not be determined readily nor could the reasons surrounding the evaluations be communicated easily. Thus, the analysts would be most effective if they concentrated on modeling TSU rather than on trying to represent all value categories. So, we would recommend a moderately comprehensive value measure (A3212) rather than a completely comprehensive one (A3213). This was done in the actual analysis.

The TSU valuation was decomposed extensively into its constituent parts (A3222) to enable an easier assessment. Because of the decomposition, each assessment considered only a single area of expertise. This choice was indicated because the valuation of TSU was very difficult to make (S1512). An additional important choice was the way to decompose the TSU. TSU was decomposed by functions rather than by components. That is, the proposals would be evaluated on how well they performed functions like jamming and deception rather than on how well their components, such as antennas and receivers, were designed.

Although a component decomposition combined with a large simulation of the systems would have provided a somewhat better evaluation, such an analysis was not nearly as efficient as the functional decomposition. A decomposition by components would have resulted in a much costlier and time consuming analysis because it would have required a large simulation model of the interactions of a system's components in order to evaluate it (because the components of an EW system interact heavily). The functional decomposition focused attention directly on the performance of the system and thus offered a much cheaper and quicker analysis.

The method of swing weights, similar to that explained in Section 2.3.2 (the Foreign Policy Case) above, was used to combine the assessments of the elements of TSU into a single index. In this case, however, both multiplicative and additive combination rules were used. The major reasons for using swing weights were the same in this case as in the Foreign Policy Case. Specifically, this method promoted an efficient elicitation of values and easy communication of the evaluations. The multiplicative combinations were included because the assessors judged that some low scores on some value elements would drive down the overall TSU, regardless

of the scores on other value elements; a multiplicative combination exhibits this behavior. (See pp. 22-24 of Hays, O'Connor, and Peterson [1975] for a more detailed description of the multiplicative combination procedure.)

Model of uncertainty - Three main analytic choices were indicated for the model of uncertainty. First, scenarios were used to describe the uncertain environment in which the EW system would have to operate. Second, certainty equivalents were assessed for each proposal's uncertain performance on each element of value. Third, a simulation model was not used, even though one was available.

The main reason for using scenarios to describe uncertain events (A421) was that scenarios were issued to the contractors to be used in their design effort. Since the design-to-cost policy did not allow the Navy to state its needs in terms of strict performance requirements, the scenarios provided a way for it to specify what it wanted the EW systems to do. In particular, the Navy told the contractors to propose EW systems that would operate in eight scenarios. In addition, the use of scenarios promoted a logical valuation. Since valuation was difficult (S1512), methods were needed to make this task easier for the assessors. In this case, value assessments were easier if the assessors visualized the different proposed systems operating in different scenarios. Thus, the use of scenarios enabled the assessors to think concretely about the way that the systems would operate, and this enabled the assessors to assign accurate values.

Certainty equivalents were used to assess the performance of each proposed system along each element of value (A3110). Originally, the analysts considered modeling the uncertain performances of the proposed EW systems as probability distributions (A3112). However, they later found that such a structure would be too time-consuming to implement

(P212) and that the experts were comfortable in making direct judgments of certainty equivalents. Thus, the simpler certainty equivalent method was indicated.

Although a model was available to simulate the performance of the proposed EW systems, this model was not used (A5310). A simulation would have been very costly (P224) and time-consuming (P215), and the static nature of the operation of an EW system permitted the alternative formulation of the value method described above. A simulation model may have been recommended if more dynamic systems, such as weapon systems, were being evaluated. A simulation model can represent the dynamic aspects of the situation (such as reloading and reacting to an enemy's actions) that cannot be represented in the static valuation model that was used.

4.4 Conclusions

The taxonomic framework seems to serve as a useful guide, in this case, for a decision maker to decide on the proper amount of decision analysis. However, the stakes and justification needs of this situation were sufficient to indicate a large analysis, though the analysis budget was ultimately sufficient to determine the size of the actual analysis.

The taxonomies also offer a language that is useful in explaining the most important analytic choices. In addition, the taxonomies, had they been available, may have improved the actual analysis. In particular more of the analysts' attentions could have been focused on the display and communication needs of the situation. On the other hand, the taxonomies are not presently developed to a level of detail that permits a discussion of all major analytic choices. In particular, the choices to use external validation and to decompose value by function rather than by component could not be explained within the taxonomies as they are presently developed.

4.5 Appendix: Situation Characterization

This appendix presents a characterization of the Design-to-Cost Case along the dimensions of the situation taxonomy that is described in Section A of Volume III. A summary of this characterization is presented in Table 4-2.

1 Decision Substance

11 Basic Situation

1111 Current choice. The problem was to make an immediate evaluation of the six contractors' proposals.

1123 Few recurrences. The present analysis would evaluate the contractors for the purpose of selecting two of the six to fund for further development. It was anticipated that a similar analysis could be used to decide between the two finalists at a later time.

12 Options

1212 Narrow options. The options were how to evaluate the six proposals with respect to their military worth.

1221 Clear options. The options were clearly defined to evaluate the six proposals.

1232 Few options. Only six proposed systems were under consideration

1243 Adaptive. The task of evaluating proposals for military systems was a familiar one for the

1 DECISION SUBSTANCE

11 BASIC SITUATION

- 1111 current choice
- 1123 some expected recurrence

12 OPTIONS

- 1212 narrow
- 1221 clear
- 1232 few
- 1243 adaptive
- 1251 static

13 EASE OF DECISION

- 1313 difficult
- 1321 familiar to decision maker
- 1332 information is the key consideration

14 STAKES

- 1443 maximum option impact about $10 million

15 OUTCOME VALUATION

- 1512 difficult net valuation
- 1523 many value dimensions
- 1531 approximate metric
- 1541 low natural combinability
- 1553 long time horizon
- 1562 moderately difficult component valuation

16 OUTCOME UNCERTAINTY

- 1613 many uncertainties
- 1623 easy to assess
- 1632 medium amount of uncertainty
- 1654 lends itself to both direct and indirect judgement
- 1661 low hindsight monitoring

2 DECISION PROCESS

21 REACTION TIME

- 214 months

22 ANALYTIC PROCESSES

- 2216 many input sources
- 22212 group of decision analysis
- 22223 consultants
- 2232 some constraints on analytic method
- 2240 no constraints on documentation
- 2252 high interest in trying new analysis tools

23 ORGANIZATIONAL PROCESSES

- 23112 scheduled decision
- 23123 initiated by a superior
- 23214 to provide information
- 23222 shared responsibility
- 2330 no coordination with other decisions
- 2342 pre- and post-decision justification
- 2352 very controversial
- 2372 "rational actor" model

24 DECISION MAKER CHARACTERISTICS

- 24114 staff member
- 24210 unfamiliar with decision analysis

25 RESOURCES AVAILABLE

- 2510 computer not readily available
- 2532 decision analysis specialist
- 2542 decision maker available
- 25512 assessors available
- 2562 modest budget available

Table 4-2

SUMMARY CHARACTERIZATION OF DESIGN-TO-COST SITUATION

program manager. (The method of evaluation, however, was new, as stated in 1321 below.)

1251 Static. The evaluations made would be final.

13 Ease of Decision

1313 Difficult decision. The evaluations of the systems were not at all obvious; none of the six contractors appeared either totally superior or inferior to the others.

1321 Familiar to decision maker. The project manager was familiar with evaluating contractors' proposed systems, but he was unfamiliar with the design-to-cost procedure, as this was its first application.

1332 Information is key. The key determinant of a good analysis was how well it provides the evaluation information needed by the SSAC to make its recommendation.

14 Stakes

1443 Maximum option impact of about $10 million. This figure is an estimate that a wrong choice of contractors could cost about 10% of the total proposed system. (The 10% estimate considers both the cost due to a degraded system and the cost of a possible delay due to a justifiable protest by one of the contractors who was rejected.) The total system purchase would be approximately 30 units costing $1.2 million each, 50 units costing $500,000 each, and 120 units costing $300,000 each.

15 Outcome Valuation

1512 Difficult net valuation. Because of the design-to-cost policy, the systems could not be evaluated on the basis of their cost alone. Evaluation would have to be on the basis of the system's performance in a number of different military scenarios, and thus the evaluation was difficult.

1523 Many value dimensions. The operational performance of the system's many parameters had to be considered in many operating situations. An example of one of the hundreds of value dimensions is the effectiveness of the system's sensors in identifying enemy decoys in an open-sea battle scenario.

1531 Approximate metric. Most of the system parameters could be characterized in metrics such as the number of targets that the system could detect before saturation. However, these metrics were only indirectly related to the system's military value.

1541 Low combinability. The metrics for the many components did not combine naturally.

1553 Long time horizon. This decision would help determine the Navy's EW capability, and its effects would extend over several years.

1562 Moderately difficult component valuation. Since the options were developed only to the stage of proposals, it was not easy to determine with accuracy how each would perform.

However, each valuation could be made, with some difficulty, as a judgment of the certainty equivalent of a system's uncertain performance.

16 Outcome Uncertainty

1613 Many uncertainties. Not only was each system's performance on each value dimension uncertain, but situations in which the systems would have to operate were also uncertain.

1623 Easy to assess. Although the problem contained many uncertainties, they were all fairly easy to assess.

1632 Medium amount of uncertainty.

1654 The uncertainties lent themselves to both direct and indirect judgment. The probabilities of the scenarios could be assessed directly, but the uncertain performance was easiest to assess from a decomposed model of value.

1661 Low hindsight monitoring. The decision maker could never expect to know with certainty whether his valuations were correct (because the rejected systems would never be built).

2 <u>Decision Processes</u>

21 Reaction Time

214 Months. Evaluations of the systems were required within 6 weeks of when the analysis was first considered.

22 Analytic Processes

2215 Many input sources. Two Navy EW experts provided most of the assessments; however, they often needed to obtain their information from experts in other substantive areas.

22212 and 22223 A group of decision analysis consultants were readily available to perform the analysis.

2232 The analysis had to be performed within the guidelines of the design-to-cost policy that is explained in Section 4.1.1 above.

2240 The form of the documentation of the evaluations was not constrained.

2252 Because the design-to-cost policy was so new, the decision maker was interested in trying new analytic tools to help in his evaluations.

23 Organizational Processes

23112 These evaluations were known about and scheduled around the time that the RFP was issued.

23123 The evaluation was initiated by the SSA, who would eventually decide which contractors to retain.

2314 The results of the project manager's evaluation would serve as the basis for the SSAC's recommendation for the SSA's decision.

232222 Shared responsibility. The SAC, SSAC, SSAB and several other experts all shared responsibility for various aspects of this decision.

2330 This decision did not need to coordinate with others.

2343 Pre- and post-decision justification. Any evaluation that the SSAB made would be very controversial and thus would need to be defended to the SSAC, the SSA, and to the bidding contractors. The evaluation would need to be explained to the SSAC and the SSA before a decision is made, and to the contractors after a decision is made.

2352 Very controversial. This decision evaluated six strongly competitive contractors and was very controversial.

2372 "Rational actor" model. It was important for the evaluation to be carefully reasoned and to represent the view of the U.S. as a whole.

24 Decision Maker Characteristics

24114 The project manager was a staff member and did not have line authority for deciding which contractors to retain.

24210 The project manager was unfamiliar with decision analysis.

25 Resources Available

2510 A computer was not readily available to the analysts.

2532 Decision analysis specialists were readily available as consultants.

2542 and 25512 The decision maker and substantive experts were readily available throughout the analysis. At least one person was available on a full-time basis for the entire 6-week period.

2562 Modest budget. An analysis budget of about $20,000 was available.

5.0 CASE 4: A NAVY TASK FORCE COMMANDER'S TACTICAL DECISION AID

5.1 Introduction

This case refers to a portion of a research effort performed for the Office of Naval Research to develop tactical decision aids for Navy task force commanders (CTF's). The case below is presented from the point of view of a CTF who is faced with a decision problem during the execution phase of a mission. The particular aid referred to here is the combined parametric/Bayesian model that was first identified in Brown, Peterson, Shawcross, and Ulvila (1975) and then developed further in Peterson, Randall, Shawcross, and Ulvila (1976). The reader should refer to Brown, et.al. (1975) for a technical description of the aid and the threat setting for which it was developed.

5.1.1 Problem background - A Navy task force commander (CTF) who is in the process of executing a planned mission may be faced with contingencies that would force him to change his plan. Some such contingencies include:

- o severe weather conditions
- o a required search and rescue (SAR incident)
- o an unexpected attack by a minor power
- o an unexpected attack by a major power

A threat that concerns a CTF greatly is the enemy anti-ship missile (ASM) threat, and especially the threat of a surprise attack from an aircraft/submarine combination. (In this combination, the aircraft serves as a targeting platform for the submarine, which is the attack platform that launches the missile.)

Our investigation of this threat, which is reported in Brown, et.al. (1975), indicated that this threat is serious, probable, and predictable. The threat is serious enough to justify an analysis by the CTF; it jeopardizes the survivability of the task force. The threat is probable enough to justify a prior analysis; it may occur across a range of geographical and political situations. The threat is predictable and stable enough to permit a prior analysis that would still be appropriate, with minor adjustments, when the contingency arose; it is characterized by an established sequence of observable indicators.

5.1.2 Use of decision analysis - At this time, the CTF's staff does not possess a decision analysis capability, nor will such a capability be added to the staff within the near future. Thus any aid that uses decision analysis techniques must be designed so that it can be operated by people who are unfamiliar with its technicalities. However, such an aid may be built initially by decision analysts if it can be adjusted by the CTF and his staff. This is the perspective that was taken by the decision analysis researchers.

5.2 Performance Determinants of a Good Analysis

In this particular case, the situation dictated that a good aid was one that performed well in four performance categories. The aid had to operate quickly, provide logical decisions, perform pre-choice activities well, and improve information handling.

Since a CTF would have only a few minutes or hours to react to an air/submarine ASM attack (S211, S212),[1] the most

[1] Parenthetical references that begin with the letter "S" are to the situation taxonomy characterization of this case, which is presented in Section 5.5 below.

important performance feature of an aid to help a CTF in this situation would be to operate very quickly (P2152).[2] The aid would have to accept inputs quickly (P2122), perform calculations quickly (P2132), and provide output that could be interpreted quickly by the CTF (P2142). This last aspect, quick interpretability, is an especially important consideration because the CTF is unfamiliar with decision analysis (S24210). Notice that this requirement for speed concerns the operation of the aid, not its construction, which does not have to be particularly fast.

The overall logic of the choice (P114) is very important because the choice of responses to the ASM threat is difficult (S1313) and controversial (S2352), and because it involves high stakes (S1444). In addition, sound predictions (P113) are an important component of logic because the intent of the enemy is both critical to the decision and very difficult to assess (S1621). Also, the overall logic is improved by an effective disaggregation of the decision problem (P112) because several people have responsibilities for different aspects of the decision (S2212).

Because this situation deals with a contingent choice (1112) where the actual decision will need to be made quickly (S211) by a decision maker who is unfamiliar with decision analysis (S24210) and who will have no decision analyst available (S2531), activities preceding the choice processes (P31) are very important. With this category of activities, the aid should provide a good pre-analysis of the anticipated decision (P314), identify when a decision is required (P312), and monitor the environment for indications that a problem exists (P311).

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[2]Parenthetical references that begin with the letter "P" are to the performance measure taxonomy, which is described in Section C of Volume III.

Finally, because a vast amount of information, much of it irrelevant, will be available to the CTF when he has to make his decision, an effective aid must be able to identify and process the relevant data efficiently (P331).

5.3 Analytic Choices

The recommended analytic options for this case are summarized in Table 5-1. The following sections explain the reasoning behind the most important of these choices. In this case, all analytic choices were made by the analysts, not the decision maker.

5.3.1 Choice of the amount of analysis - Section 3.1.2 of Volume I explains guidelines for determining the proper amount of decision analysis in terms of situational characteristics. This case can be characterized along most of these situational dimensions as follows.

Important factors favoring a large amount of decision analysis:

- The decision options are clearly defined (S1221). The composition of a naval task force and the range of its operations are clearly defined.

- The choice is difficult (S1313). The task force's response to this ASM threat is not easy, especially since the enemy is expected to try to conceal his intent.

- Choosing the best course of action is the key determinant of a good decision (S1334).

1 USER'S OPTIONS

11 USE DECISION ANALYSIS AT ALL?

112 yes

12 DOLLAR AMOUNT

123 high

13 ROLE OF DECISION ANALYSIS

1311 private aid
1322 optional decision
1331 contingent analysis
1343 both optimization and display
1351 communication

14 ORGANIZATION

1412 three decision makers and staff provide inputs

15 RESOURCES

1521 use a computer

2 MODEL APPROACH OPTIONS

21 COMPLEXITY OF ANALYSIS

211 simple

24 BALANCE OF EFFORT

2412 appreciable option definition
24213 high uncertainty modeling
24222 high value modeling

3 INPUT STRUCTURE

31 UNCERTAINTY

3112 model with probability distribution
3141 low level of detail

32 VALUE

3213 highly comprehensive
3221 modest decomposition
32312 single abstract index
32411 linear value function

4 INPUT SPECIFICATION

42 EVENTS

4222 specific

43 VALUE CRITERIA

4319 abstract unit
4322 "floating zero" base

44 INDIRECT ASSESSMENTS

4421 Bayesian updating
4431 decomposed assessment

5 OUTPUT

51 SPECIFICATION

5111 preferred decision
5121 single value for each option

52 DISPLAY FORMAT

5211 & 5221 computer graphics

6 MODEL MANAGEMENT

61 MODEL DYNAMICS

61533 high input iteration

62 CONTINGENT ANALYSIS INPUT SEQUENCE

6211 enter values early
6231 enter likelihoods early
6242 enter data late

Table 5-1

SUMMARY OF ANALYTIC CHOICES FOR A NAVY TASK FORCE COMMANDER'S DECISION AID

- The stakes are very high (S1444). A wrong decision could provoke a major confrontation between the US and the enemy.

Important factor against decision analysis:

- The decision maker, the CTF, is unfamiliar with decision analysis (S24210), and he will not have a decision analyst available when he uses the aid (S2530).

Other factors in favor of decision analysis:

- Valuation of outcomes is difficult (S1512). The CTF must weigh the effects of his decision on the success of his mission, the damage sustained by his forces, and the international political position of the U.S.

- The key uncertainty, the intent of the enemy, is difficult to assess (S1621).

- A ship-board computer is readily available for the CTF's use (S2512).

- A large analysis budget would be available (S2563).

Other factors against decision analysis:

- The choice is a contingent one (S1112).

- Less than one expected occurrence (S1121). It is uncertain whether any particular CTF will ever face this enemy ASM threat.

- Very short reaction time (S211). The CTF will ultimately have only a few minutes to react to an ASM attack.

In this case, more factors argue for a large analysis than argue against it. Most importantly, the stakes involved in the decision are high enough to offset the fact that the decision is a contingent one with less than one expected occurrence. That is, even though the probability that a particular CTF will ever face an enemy air/submarine ASM threat is low, the consequences of a wrong decision are important enough that an analysis is still justified. Furthermore, because any decision aid would have to be operated by a CTF who is untrained in decision analysis without the assistance of a decision analyst, if decision analysis is used at all, a large amount must be used. A large analytic effort is required to adapt decision analysis techniques so that they can be used by people who are unfamiliar with the methodology. Overall, then, we recommend a large amount of decision analysis for this situation.

5.3.2 Other analytic choices - In developing this aid, the analysts had to keep in mind the setting in which the aid would be used, that is, aboard a ship by a Navy task force commander. Thus, most of the analytic choices were made considering ways to package decision analysis techniques into an aid that could be used, without the help of a decision analyst, by a person untrained in decision analysis. Six major analytic choices were made regarding this aid. A choice was made to model the contingency in advance, to build a parametric aid, to use a Bayesian hierarchical inference structure, to display the results in a "probability triangle," to plan for a highly interactive operation of the aid, and to use the "swing-weight" method of modeling value.

The first analytic choice was to model the enemy air/submarine ASM threat contingency in advance. That is, to develop a model of this contingency well in advance of its occurrence and store the model in a computer, to be recalled as a need arises. This advance modeling consisted of several parts. The CTF's value system was modeled in advance (A6211); the prior probabilities needed for the analysis were modeled in advance (A6221); likelihoods, which expressed the diagnosticity of data that was anticipated to arrive as the threat developed, were stored in advance (A6231). Data, which signaled the development of the threat, were not modeled in advance but were left to occur as the threat developed (A6242).

These choices to build most of the decision model in advance were made because the aid would have to operate very quickly (P2111, P2132, P2152) when the threat actually occurred; the only way to provide the required speed was to perform most of the analysis in advance. Characteristics of the threat were also important for advanced modeling. In particular, the contingency had to be so predictable that only minor last-minute adjustments would be required to bring the model in line with the actual contingency, when it occurred. Our evidence indicated that an enemy air/submarine ASM attack would develop according to a sequence of events that were highly stereotyped and thus could be predicted in advance.[3] In addition, the range of the CTF's available option could also be predicted in advance. This amount of predictability allowed the analysts to assume that the structure of the model could be pre-programmed, that the probable indicators of threat and their diagnosticity could be pre-programmed, and that the CTF's decision options and value structure could be anticipated approximately and pre-programmed.

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[3]In the actual development of the aid, the analysts sought out situations that appeared to exhibit this kind of predictability and thus supported the development of a pre-programmed aid.

In addition, storing an analysis ahead of time permitted the CTF's environment to be monitored for characteristics that indicated that a decision was needed (P311, P312). This monitoring was possible because the model could be used to process data and alert the CTF when enough evidence was present to consider changing his mission plan. Modeling likelihoods in advance allows the aid to improve the handling of information (P331) by identifying the important information so that it can be given priority in processing. Building the model ahead of time also promotes a good pre-analysis of the threat (P314) because it allows the CTF to simulate the threat through exercising the model.

The second major analytic choice was to use a parametric decision model that processed inputs in a manner to produce decision thresholds on a single parameter. In this case, these thresholds were stated in terms of the enemy's intent to use his air/submarine ASM capability. A parametric model was chosen mainly because it is fast and especially because that output is stated in terms of a single parameter that can be grasped quickly by the decision maker (P2142). The decision to use the probability distribution of the enemy's intent as the parameter was made because this parameter appeared to capture the essence of the threat situation in a way that enhanced its predictability, and predictability is the key feature that permits a pre-modeling.

The third major analytic choice was to use a simple Bayesian hierarchical model of the uncertain quantity, the enemy's intent. This particular model was composed of two analytic components. It used Bayes' Theorem to process information bearing on the enemy's intent (A4421), and it decomposed the assessment of the probability of intent (A4431) in a hierarchical way. This analytic choice promotes an effective disaggregation of the model (P112) by allowing the

opinions of various experts to impact on the probability assessment. This choice was further indicated because the probability assessment lent itself naturally to this decomposed assessment technique (S1653) so such a technique could improve the predictive power of the aid (P113).

The fourth major analytic choice was to display the results in a "probability triangle" using a graphic computer display (A5211, A5221). A "probability triangle" (see pp. 3-15 through 3-19 of Brown, et.al. [1975] for a technical description) can display graphically probabilities, thresholds, and the relationship between them for an uncertain quantity that can be characterized by three states. This display was chosen because it is a form that can be readily interpreted by the decision maker (P2142), allowing him to quickly grasp the most important aspects of his decision situation. While this form of graphic display is a highly desirable form of output, it is possible only in situations where the essence of the uncertainty can be simplified to consider just three possible states (A3141).[4] Fortunately, in this case such a simplification was possible without seriously over-simplifying the analysis. This model was programmed on a computer because that is the only way that the inputs could be accepted and the output calculated quickly enough (P2122, P2134) to be useful in a developing threat situation. Computer graphics were needed in order to display the "probability triangle" (A5211, A5221).

The fifth analytic choice was to use the method of "swing weights" to model the CTF's value structure. Similar to the method used in the Foreign Policy Case (Section 2.3.2

[4]A research effort directed at seeking similar graphic displays for events that contain more than three states is reported on pages 22-26 and 91-115 of Peterson, et.al. (1976). The conclusions of this effort are, at this time, too tentative to recommend a method for more than three states.

above), the valuation was defined by specifying, on each of three value dimensions (S1522), the relative value to the CTF of each action/event combination on a 0-to-100 scale and then aggregating across the value dimension by weighting each scale to obtain a weighted average net value for each action/event combination. This method was chosen mainly because it enables a decision maker who is untrained in decision analysis to interpret the values quickly and accurately and because it is a method that enables fast sensitivity analysis (A61533) (see the discussion of sensitivity analysis in the following paragraph).

The sixth important analytic choice was to design the aid in a way that would promote sensitivity analyses (A61533) by varying the model inputs and seeing the results quickly. Such an aid would allow the CTF to change the stored values easily and see the effects of these changes immediately. A large amount of sensitivity analysis promotes a good pre-analysis of the decision situation (P314) by allowing the CTF to thoroughly examine the effects that change inputs have on the decision and thus gives him a feel for the robustness of his decision options. By allowing for each change in the input values, this aid also improves the logic (P144) of the model by allowing last-second adjustments to the model to incorporate unforeseen events.

5.4 Conclusions

The taxonomies appear to be very useful for determining the proper amount and type of decision analysis for this case. In particular, the taxonomies appear to provide a good indication of what kinds of decision analysis techniques are useful for a contingent analysis and what additional situational characteristics are required to justify the use of any decision analysis in the contingent choice situation. However,

in this case, the taxonomy appears to be more useful from the decision analyst's standpoint than from the decision maker's standpoint. In particular, the use of decision analysis at all depended critically on the specific analytic techniques, and these techniques can probably be chosen only by an analyst.

5.5 Appendix: Situation Characterization

This appendix presents a characterization of this case along the categories of the situation taxonomy presented in Section A of Volume III. This characterization is summarized in Table 5-2 and explained below.

1 Decision Substance

11 Basic Situation

1112 Contingent choice. The decision facing the CTF is what actions to take if an ASM threat begins to develop.

1121 Less than one expected occurrence. While this threat could present itself in a range of geographical and political situations, it is not certain that a particular CTF will ever be faced with the threat.

1131 Operating act. The CTF will consider actions to reposture his forces against the threat, including launching an attack against the enemy aircraft or submarine.

12 Options

1212 Narrow options. The CTF will make commitments of the forces under his direct control.

1 DECISION SUBSTANCE

11 BASIC SITUATION

1112 contingent choice
1121 less than 1 expected occurrence
1131 operating act

12 OPTIONS

1212 narrow
1221 clear
1232 few
1252 dynamic

13 EASE OF DECISION

1313 difficult choice
1321 familiar to the decision maker
1334 choice is the key consideration

14 STAKES

1444 high maximum option impact

15 OUTCOME VALUATION

1511 moderately difficult
1522 medium number of value dimensions
1530 no natural metrics
1541 low natural combinability
1562 moderately difficult component valuation

16 OUTCOME UNCERTAINTY

1612 few important uncertainties
1621 difficult to assess
1653 lends itself to indirect techniques
1663 high hindsight monitoring

2 DECISION PROCESS

21 REACTION TIME

211 minutes

22 ANALYTIC PROCESSES

2212 few sources of input

23 ORGANIZATIONAL PROCESSES

23211 CTF will make a final decision
23221 little dispersion of responsibility
2342 post-decision justification
2352 very controversial

24 DECISION MAKER CHARACTERISTICS

24113 flag officer
24210 unfamiliar with decision analysis

25 RESOURCES AVAILABLE

2512 computer readily available
2522 strong staff
2530 no decision analyst

Table 5-2

CHARACTERIZATION OF NAVY TASK FORCE COMMANDER'S TACTICAL SITUATION

1221 Clear options. The CTF will decide among the clearly defined actions that he can take with his forces.

1232 A few decision options must be considered.

1252 Dynamic. Some of the actions that the CTF might take could be modified by his later actions. For instance, he could take an increasingly hostile stance toward the threat; he does not need to make an irrevocable decision to attack immediately.

13 Ease of Decision

1313 Decisions in this threat situation are very difficult, especially since the enemy can be expected to try to conceal his actual intentions.

1321 A CTF if familiar with the choices available to him to counter the enemy ASM threat.

1334 The CTF's primary concern is to choose his best option.

14 Stakes

1444 The stakes in this decision are very high. A wrong decision could conceivably provoke a major military confrontation between the US and the USSR.

15 Outcome Valuation

1511 Overall, it is very difficult to compare the attractiveness of the possible outcomes.

1522 A moderate number of value dimensions are important. Those that are most immediately important to the CTF are: 1) his success in completing a primary mission; 2) the damage sustained by U.S. forces in a confrontation with the enemy; and 3) the political repercussions of his actions.

1530 No natural metrics exist on any of the three value dimensions mentioned in 1522 above.

1541 The value dimensions do not combine naturally.

1562 The outcomes are fairly difficult to evaluate along the value dimensions.

16 Outcome Uncertainty

1612 A number of uncertainties about the way that the ASM threat may evolve are potentially important for the CTF's decision. However, these uncertainties can be summarized adequately by the uncertainty about the enemy's intent to use his ASM capability.

1621 While the important uncertainties can be summarized nicely in terms of the enemy's intent, enemy intent is a very difficult uncertainty to assess.

1653 The assessment of enemy intent lends itself to the use of indirect elicitation techniques

especially because an ASM attack will be accompanied by a sequence of intelligence reports of the enemy's activities.

1663 High degree of hindsight monitoring. The outcome of the CTF's decision will be known to him soon after he takes an action.

2 Decision Process

21 Reaction Time

211 to 212 Minutes to hours. The CTF ultimately has only a few minutes to react to an ASM attack, but he may have several hours to react to the early signs that such an attack might occur.

22 Analytic Processes

2212 or 2214 Few sources of inputs. The CTF (or his surrogate) will provide value inputs and members of his staff or other intelligence experts will provide inputs concerning the uncertainties.

23 Organizational Processes

23211 The CTF will make the final decision.

23221 A small group of people will have responsibility for parts of the decision. For example, intelligence analysts will be responsible for providing estimates of the enemy's intent and the CTF will be responsible for taking an action.

2342 The CTF may have to justify his actions after the fact.

2352 Any decision that the CTF makes concerning his response to a Soviet ASM threat will be controversial.

24 Decision Maker Characteristics

24113 A CTF is a flag officer.

24210 The CTF is not likely to be familiar with decision analysis.

25 Resources Available

2512 A ship-board computer would be readily available.

2522 A CTF has a large staff readily available.

2530 No member of a CTF's staff is a decision analyst; thus no decision analyst would be available while the aid would be used. However, a decision analyst would be available to help develop the aid.

6.0 CASE 5: PREDICTING NATO'S RESPONSE

6.1 Introduction

This case refers to a study performed for the Studies, Analysis, and Gaming Agency of the Office of the Joint Chiefs of Staff and reported in Brown, Kelly, Stewart, and Ulvila (1977) and Brown, Kelly, Stewart and Ulvila (1975/2). The study was an attempt to predict the behavior of NATO in response to the question, "If the Warsaw Pact countries were planning to attack at the end of a 30-day mobilization cycle, at what point in time after the pact began to mobilize would NATO initiate a state of reinforced alert?" Since the main goal of the study was to develop a model for predicting the behavior of NATO rather than to analyze a decision problem, only a fraction of the analytic choices were relevant. For this reason, the discussion of the case below is much shorter than that of the other cases in this report.

6.1.1 Problem setting - Early in 1974, the Studies, Analysis, and Gaming Agency (SAGA) of the Office of the Joint Chiefs of Staff was interested in studying the effects that alternative Multiple and Balanced Force Reduction (MBFR) actions would have on NATO's capability to respond to an attack by the Warsaw Pact countries. Within this broad topic area, SAGA was most interested in developing a method of predicting when NATO forces would move to a state of reinforced alert if the Pact was planning to attack after a particular 30-day mobilization scenario.

6.1.2 Use of decision analysis - The study approached the problem of predicting NATO's reaction to a Pact threat by considering the total lag in NATO's response to be composed of two parts. The first part was the lag in time between the

Pact's mobilization and a recommendation by the Supreme Allied Commander in Europe (SACEUR) to the North Atlantic Council (NAC) for NATO to mobilize. The second part was a lag between the receipt of this recommendation and a decision by the NAC to move the NATO forces to a state of reinforced alert.

Within this framework, the major analytical effort was devoted to developing a prescriptive model of SACEUR's behavior. This effort took the form of a "rational choice" model to predict when in the Pact's mobilization cycle SACEUR would prefer to see NATO forces mobilize.

Initially, the modeling effort made strict assumptions about the mobilization scenario, SACEUR's behavior, and NAC's behavior. Later in the analysis, some of these assumptions were relaxed informally.

6.2 Analytic Choices

6.2.1 Amount of decision analysis - Since the main purpose of this study was a prediction rather than a decision, many of the situation characterizations favoring decision analysis that are presented in Section 3.1.2 of Volume I are irrelevant to this case. Most importantly, the characterizations that are concerned with the decision options and with validation, cannot be established meaningfully in this case. However, other characterizations are relevant. With respect to these characterizations, this case can be classified as follows.

Situations characteristics strongly favoring decision analysis:

- The analysis was concerned mainly with inference (S1333).

- Several sources of uncertainty inputs needed to be considered (S2214).

Situation characteristic strongly against decision analysis:

- Choice was not a consideration (S1334).

Additional characteristic favoring decision analysis:

- Uncertainties were difficult to assess (S1621).

Additional characteristic against decision analysis:

- The "rational actor" model was a poor approximation of the decision-making process (S2371).

Since so few situation characteristics were relevant in this case, the taxonomy does not serve a very useful purpose in deciding how much analysis is justified. Our recommendation in this case is that a moderate amount of analysis is appropriate, mainly because decision analysis techniques can be very useful in making difficult, important inferences.

6.2.2 Other analytic choices - The decision analysts made five major analytic choices in this case. First, they chose to devote the major portion of their effort to a prescriptive model of when NATO would mobilize. Second, they chose to use scenarios to represent uncertainties. Third, they chose to start with a fairly simple approximate analysis. Fourth, probabilities were elicited directly. Fifth, the assessments of individual experts were pooled to obtain the final probability estimates.

As mentioned in the introduction, most of the analytical effort in this case was devoted to developing a "rational choice" model of SACEUR's decision process. This model was a prescriptive decision analysis model that attempted to identify when, in a Warsaw Pact 30-day mobilization and attack cycle, SACEUR would prefer to see NATO forces move to a state of reinforced alert. The critical feature of this model was the treatment of the action "NATO mobilize." The model treated this as an action in the classical form of preposterior analysis (A3131). That is, for each day in the Pact 30-day attack cycle, the model analyzed whether the action "NATO mobilize today" was preferable to the action "NATO wait," and the day that mobilization was first preferred determined the SACEUR lag. Such a model is appropriate when the "rational actor" model is a close approximation of the decision-making process (S2372) and when the structure of all uncertainties can be predicted accurately. However, these conditions were not met in this case, and this type of model should not have been structured as an inference model to assess directly the likelihood that NATO would mobilize. In particular, a direct group assessment of the probability of NATO's actions would have provided a better, less expensive, and less complex prediction model than the "rational actor" did.

A scenario (A421), a specific description of the information that NATO might receive if the Pact were mobilizing on a 30-day attack cycle, was used to describe the event space of the Pact's actions for two reasons. First, the event space was very complex; the Pact countries could take a wide range of political and military actions in preparation for an attack on NATO. Second, it was impossible for the analysts to obtain a convenient summary of the Pact's actions for the purpose of predicting NATO's reactions. In such a situation, a scenario is often the best way to characterize the event of a Pact attack because the scenario provides a concrete description of

events that enables assessors to provide accurate probability and value judgments.

A very simple (A211) model that used many approximations (A231) was indicated for similar reasons. A simple model provided the best cost effectiveness; the improvement in logic that a more complex analysis would provide could not justify its greater cost, especially within the range of the analysis budget of $60,000. An approximate analysis that contained a very simplified tree structure and relied heavily on the use of certainty equivalents (A3110) to aggregate uncertainties was indicated mainly because the assessors were not readily available during the analysis (S25511). In addition, the analysts felt that, in this situation, an approximate analysis could save a great deal of cost at little expense in terms of logic.

The probability assessors were accustomed to making direct assessments of probabilities based on intelligence information. Therefore, the analysts could make the best use of the assessor's time, which was scarce (25511), by eliciting the probabilities directly rather than indirectly (e.g., using such techniques as Bayes' Theorem (A4421).

Finally, the analysts asked each expert for his assessments individually and then the analysts averaged the individual assessments to estimate the group's opinion (A4540). This method contrasts with the alternative of having the experts resolve their differences to arrive at a group assessment (A4541) (e.g., using the Delphi Technique). Such a consensus generally requires the assessors to be much more available than they were in this case. In addition, techniques used to elicit a consensus generally are more costly and time-consuming than the averaging technique. However, the averaging technique generally does not provide inputs that are as sound as those provided by a group assessment. For this reason, the

logical consistency of the inputs was checked by pooling several models (A6121) of the same inputs. In this case, the prediction of the SACEUR lag that resulted from using the average of the probability assessments was in general agreement with a direct assessment of the SACEUR lag. The combined procedure of averaging the assessments and checking the results with a pooling of models provided an analysis that was much cheaper and nearly as good as would have been provided using a group-assessment technique.

6.3 Conclusions

The taxonomic framework appears to be less well suited for indicating analytic choices for this case than in the previous cases. Because the case was interested only in making inferences about NATO's behavior, most of the situation categories proved irrelevant, and classifications along these categories were impossible. Thus, the taxonomy's guidance on the amount of analysis to perform, which required classification along some of the irrelevant categories, was of little use in determining the proper amount of analysis. However, the taxonomies were useful for explaining the reasons surrounding the most important choices of analytic techniques.

6.4 Appendix: Partial Situation Characterization

Since the purpose of this analysis was to develop a model that could be used to predict NATO's action rather than to make any decision, only some of the situation characterizations were relevant in this case. For instance, all characterizations concerned with the options or the valuation were completely irrelevant. The following table, Table 6-1, and discussion include only those elements of the situation that we consider to be important in this case.

1 DECISION SUBSTANCE

13 EASE OF DECISION

1333 inference is the key consideration

16 OUTCOME UNCERTAINTY

1613 many
1621 low assessability
1633 high amount of uncertainty
1654 lends itself to both direct and indirect judgement
1661 low hindsight monitoring

2 DECISION PROCESS

21 REACTION TIME

214 months

23 ORGANIZATIONAL PROCESSES

2371 "rational actor" model is a poor approximation

24 DECISION MAKER CHARACTERISTICS

24211 unfamiliar with decision analysis

25 RESOURCES AVAILABLE

25511 low availability of probability assessors
25521 low sophistication of probability assessors

Table 6-1

PARTIAL CHARACTERIZATION OF THE NATO RESPONSE SITUATION

1 Decision Substance

13 Ease of Decision

1333 Inference was the key consideration in this situation. SAGA was interested in predicting NATO's behavior.

16 Outcome Uncertainty

1613 Many uncertainties. Uncertainties that potentially impacted on the prediction of NATO's action included:

- o Actions of Warsaw Pact countries.
- o Information that NATO would receive about the Pact's actions.
- o SACEUR's actions in response to the information.
- o NAC's actions in response to the information.

From these, several more specific ones were included explicitly in the model:

1. The probability that the Pact would attack given a particular scenario.

2. The length of the Pact's attack cycle.

3. The length of SACEUR's recommendation lag.

4. The length of NAC's action lag.

1621 The probabilities that were modeled were difficult to assess.

1633 The uncertain quantities were very uncertain.

1654 Some of the uncertainties lent themselves to indirect assessment techniques and others lent themselves to direct ones.

1661 Low hindsight monitoring. It would be very difficult for SAGA to monitor the accuracy of their prediction of NATO's behavior.

2 <u>Decision Process</u>

21 Reaction Time

214 Several weeks were available to perform the analysis.

23 Organizational Processes

2371 The "rational actor" model, which hypothesizes a unitary decision maker who makes his decisions based on reasoned judgment, does not capture the essence of NATO's complex decision making process accurately.

24 Decision Maker Characteristics

24211 The SAGA analysts, who would use the decision analysis model, were unfamiliar with decision analysis techniques.

25 Resources Available

25511 The experts who would supply probability estimates were not very available during the analysis effort.

25521 The experts who would supply probability estimates were not very sophisticated in their knowledge of decision analysis techniques.

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